CABI WORKING PAPER 2

Climate Change and Agricultural Commodities

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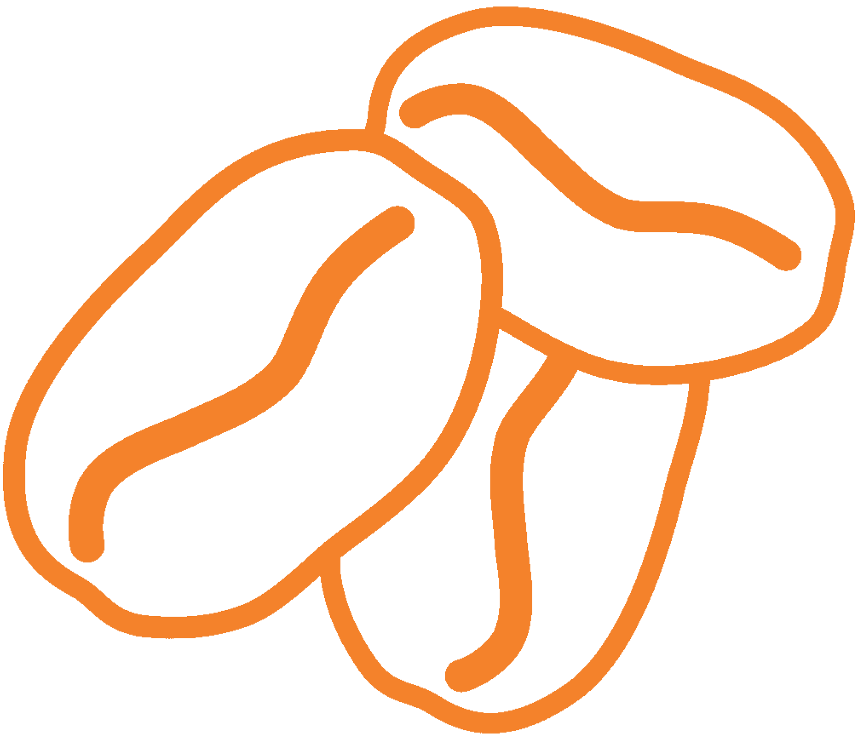

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Crop yields and changes in productivity due to climate change will vary considerably across regions and among localities, thus changing the patterns of production – in general, productivity is projected to increase in middle to high latitudes, depending on crop type, growing season, changes in temperature regime, and seasonality of precipitation

Robert T Watson

Former Chairman Intergovernmental Panel on Climate Change, 2001

…the cost of inaction will be great…

Nicholas Stern

Former UK Government Advisor and Director of Policy and Research for the Commission for Africa

It is irresponsible, reckless and deeply immoral to question the seriousness of the situation. The time for diagnosis is over and the time for action is now

Mrs. Gro Harlem Brundtland

UN Special Envoy of the Secretary General on Climate Change

Executive Summary

Agricultural commodities are any agricultural products which are traded internationally in response to demand. Climate change will have a profound impact on agricultural commodities including on their production and their productivity with consequences to both food supply and food security and many of these effects will be seen most in least developed countries (LDCs).

Without doubt, climate change is occurring and is already having a dramatic impact on climatic variability, global temperatures and sea level. Climate change will have significant impacts on agriculture, reflecting the close link between climate (temperature and precipitation in particular) and productivity and these effects are likely to have greatest effect in the LDCs of the tropical zones where productivity will decrease. A greater frequency of extreme events, heat stress, droughts and floods, will increasingly have negative impacts on crop yields. In particular, water scarcity and the timing of water availability will increasingly constrain production. Climate change will increase pest and disease outbreaks thus negatively affecting food production. Rising carbon dioxide (CO_2) levels will also have effects, both detrimental and beneficial, on crop yields. The ability of farmers and rural societies to adapt to these changes is crucial to maintaining an adequate global food supply. While demand is likely to increase, due to rising global population size primarily, climate change will challenge agricultural production and food security (locality of production, supply, volume, quality). By 2080, agriculture output in LDCs may decline by 20% due to climate change and yields could decrease by 15% on average.

Immediate research needs

There is an urgent need to do more research on the collection and synthesis of data for regions and for individual countries so that ever more accurate models are produced to inform decision makers about the strategies they need to adopt. There is a need for more action on adaptation measures in agriculture, especially in LDCs, to implement these proposed strategies so assisting farmers, extensionists, researchers and stakeholders along the supply chain to reduce the adverse effects of climate change. This is particularly important in regions where there are already large, resource–poor populations suffering from food insecurity. In the immediate future, agricultural production needs to be made more sustainable and, thus, resilient to change. To achieve this, new irrigation technologies, water conservation measures, drought resistant varieties, new cropping patterns, improved management of pests and diseases through integrated pest management (IPM), and crop diversification, particularly with alternative crops, all have to be researched to improve knowledge, and applications need to be implemented urgently.

Due to the complex physical and biophysical impacts of the interactions between the different climate variables, combined with varying irrigation, fertilizer and pest and disease management strategies and techniques, regional variability (e.g. topography, soils, and land use and management), and differences in crop growth, development, phenology, yield and resistance to drought and pests and diseases, the detailed impacts of these factors need to be investigated further. Conserving and promoting ecosystem resistance and resilience has to be a central tenet of adaptation strategies and needs to be balanced with any actions to alter or intensify agricultural production.

Specific recommendations for further research include:

- Increased precision in climate change projection with higher resolution on spatial and temporal scales;
- Linking of projections with agricultural production systems to suggest suitable options for sustaining agricultural production;
- Preparation of a database on climate change impacts on agriculture;
- Evaluation of the impacts of climate change in selected locations.

In terms of experimentation, there is a lack of knowledge of CO_2 and climate responses for the majority of crops other than cereal staples such as wheat, maize and rice, including many of importance to the rural poor (e.g. root crops, millet, brassicas). In addition to the staples such as root crops and cereals, more work needs to be initiated on how climate change will impact on traded commodities such as coffee, cotton and cocoa and how changes in production area, changes in yield, etc., will impact on the foreign exchange earnings of LDCs, in particular those whose economies are based on one or two of these traded commodities. Quality of these traded commodities is also projected to change as well as quantity. Improvement in postharvest technologies as pioneered in coffee in Africa by CABI and partners could be one way to limit the impact of changes in quality. The response of commodity pests and diseases to climate change is a knowledge gap and CABI's expertise and approach can address this research and implementation need. Changes in climate could allow endemic pests and diseases to increase in severity and could provide conducive conditions to allow pests and diseases to expand their geographical range.

Where datasets exist (public/private) of climate and preferably yield, for 50 years or more, then there is an opportunity to conduct an analysis and project changes for the near future (the next 20 years). These projections should include, if possible, changes in mean, median, standard deviation and variance of temperatures and rainfall, but also the distribution of wet spells and dry spells, absolute maxima and minima, and frequency of storms, frosts, and droughts. Valuable information can be gained to aid farmers in what to expect in the immediate future, for example dates of first and last frost, and variation in rainfall patterns. This approach will enable future climate information and forecasts and thus better management of crops and cropping systems. CABI with member countries can source such datasets and run analyses. Results and conclusions can be disseminated by various means including via the CABI Environmental Change Web Portal.

Prioritization

- Awareness raising and training on planning and zoning needed for donors and decision makers. Governments need to take firm action to protect the fertile uplands of their countries. These resources will become ever more valuable as climate change forces upslope migration of flora, fauna and human communities.
- Capacity building to reinvigorate institutions, including extension and research divisions. In general, agriculture has stagnated in development over the last 30 years, although recently, perhaps in response to environmental change and the growing threat of food insecurity and starvation, there are signs of this changing.
- Adaptation planning and implementation. In the short to medium term there is much that can be done to help farmers adapt to climate change. In areas of increased drought, options and knowledge exist to start activities in water harvesting, improved irrigation (e.g. drip irrigation, being used for coffee in Nicaragua), use of drought resistant varieties, use of shade trees where appropriate, lean water use in processing, minimum tillage, and many other technologies.
- Coordination of the efforts of governments, private organizations and other stakeholders in mitigating or adapting to the challenges of climate change.

Prevention of climate change is not possible; mitigation in agriculture (reducing the greenhouse gases released through growing and processing) is a necessary part of global efforts to reduce the rate of climate change but will not be considered in this paper which concentrates on needs for adaptation and capacity building.

Adaptation

The United Nations Framework Convention on Climate Change (UNFCCC) instigated National Adaptation Programmes of Action (NAPAs) to provide a process for LDCs to identify priority activities that respond to their urgent and immediate needs to adapt to climate change – those for which further delay would increase vulnerability and/or costs at a later stage. Key strategies will include:

- Use of new/improved varieties, crops, or rotations (longer maturing varieties, heat and drought tolerant). Alternatively, switching production from an increasingly unsuitable area to a climatic zone which is projected to be favourable for the commodity in the future;
- Designing and implementing irrigation and drainage systems;
- Adaptation to changed growing season or to a shift in timing of heat stress;
- Designing and implementing flexible cropping systems with mixed varieties, as trialled and implemented for commodities such as coffee;
- Improved use of sustainable technologies, including IPM, postharvest management and soil health, of which CABI has expertise and programmes.

However, in developing adaptation strategies, agriculturists and other stakeholders need to ensure they are not adding to climate change. Agriculture, particularly intensive production, produces approximately a quarter of global greenhouse emissions. Given predicted decreases in agricultural production and an increasing demand for food, there is an argument to intensify and expand to meet the demand. This is a real challenge as it needs to be balanced against the need to adapt to climate change and to attempt to stabilize greenhouse gas emissions. Conserving and promoting ecosystem resistance and resilience has to be a central tenet of adaptation strategies and needs to be balanced with any actions to alter or intensify agricultural production.

Capacity building

Capacity building underpins much of the foregoing discussion. Capacity building for all stakeholder groups will enable them to deal better with climate change in their own locality, country or region. Much of the focus should enable agriculturists to respond to current climatic variability, thus providing the stepping stones to adapt to future, more extreme, climatic variability.

CABI has considerable, internationally recognized expertise among the staff in the field of agricultural commodities including coffee, cocoa, cotton and oil seeds. The unique combination of in-house experts in publishing, abstracting, databases, web based portals and e-learning packages plus in-country scientists and practitioners, allows us to deliver knowledge direct to those who need it . Some of our initiatives in LDCs involve improved postharvest processing for coffee and cocoa, and IPM for many pests and diseases of our focus commodities, while community based programmes such as our farmer field schools, although originally used for IPM, have also been adapted by us to improve quality and water management for cotton production.

CABI’s recent activities

CABI (www.cabi.org) is a not-for-profit intergovernmental organization owned by a consortium of over 40 member countries and is dedicated to improving people's lives worldwide by providing information and applying scientific expertise to solve problems in agriculture and the environment. In 2007–08, CABI organized three regional consultations with its member countries in Latin America and the Caribbean, Africa, and Asia. As a result, CABI has a mandate to support its member countries in adapting to climate change and in developing management strategies and policies. CABI’s country membership, combined with a depth of practical on-the-ground experience plus our information and knowledge bases, puts us in a unique position to catalyse action by informing, updating and generally building capacity for countries, regions, communities and individuals to take concerted action now to adapt to the new realities of the impacts of climate change.

CABI has collaborated with the International Coffee Partners (Hamburg) to develop a Public–Private Project – the Coffee and Climate Change Programme – which will carry out studies with coffee farmers in four countries on practical ways to adapt to and mitigate effects of climate change. This project was approved for funding by the German government in August 2010.

Efforts are also being made to build relationships between scientists, traders and other stakeholders interested in the long term sustainable supply of commodities. CABI believes such linkages must be strengthened to deal with the reality that climate change is already affecting commodities farmers in many countries. To date this has involved awareness raising lectures at the World Coffee Conference, the Specialty Coffee Association of America, TWIN Trading, the Coffee Tea & Cocoa Conference (Hamburg), the East African Fine Coffees Association, the World Agroforestry Centre and other venues and fora.

Following the devastating floods in Pakistan in 2010, CABI has put its experience to use in the national recovery programme.

1. Background

Climate change will impact global agriculture in terms of productivity, commodities (Box 1) and food security. Agriculture affects all livelihoods, occupying approximately 40% of the land globally, consuming 70% of global water resources and affecting biodiversity at all scales; genetic to ecosystem. One of our biggest challenges is how to balance the growing demand for agricultural commodities with an agricultural resource that is increasingly under pressure. Agricultural resources and their associated supply chains need to be managed sustainably, and climate change is a major challenge to sustainable development (Box 2).

Box 1: Agricultural commodities

Definition

- Any item that is produced for which there is a demand and therefore a market.
- Any item that can be openly traded within such market.
- Grain, livestock, poultry, fruit, timber or other items produced from agricultural activities.

- One of the characteristics of a commodity is that the price is determined as a function of the market as a whole. Established commodities have actively traded *spot* and *derivative* markets.
- Important agricultural commodities, according to the OECD-FAO (2008) are: wheat, rice, coffee, tea, maize, yams, cassava, sorghum, pulses, sugar cane, sugar beet, potatoes, fruit, vegetables (beans).
- CABI has internationally recognized expertise in a range of commodities including coffee, cotton, cocoa, oil seeds, wheat and bananas.

Food security is a global issue that links with many aspects of food production, distribution, the environment and socio-economics. An estimated 2.5 billion people in developing countries depend on agriculture for their livelihoods (DFID, 2005). More than 50 developing countries, including a majority of the least developed countries (LDCs), depend on exports of three or fewer agricultural commodities, typically tropical products, for between 20% and 90% of their foreign exchange earnings. Many LDCs are also net food importers, spending more than half their export earnings on commodity markets, purchasing food imports to make up for shortfalls in domestic production. For example, 63% of all agricultural earnings from export in Ghana is from cocoa (Section 5) and this single commodity constitutes over 70% of an average farm's household income. Changes to international commodity markets can make the difference between famine, survival or surplus.

Box 2: Ecosystem resistance, resilience and services and the link with sustainable development

Every ecosystem is subject to perturbations such as climatic variability, nutrient fluctuation, loss of biodiversity, and introduction of exotic species, which can alter ecosystem structure and function. The degree to which ecosystems respond to perturbations depends on their ability to withstand perturbation and maintain normal function (**resistance**) and/or recover from disturbance (**resilience**). The dynamic nature of ecosystems endows them with a degree of resilience to change. These two components of stability, in essence, address how a system responds to disturbances and knowledge about them is key to developing ecosystem recovery and restoration efforts.

We must learn to use ecosystem resources (**services**) without compromising the ability of ecosystems to maintain their integrity (structure and function) especially through understanding how ecosystems respond to perturbation (resilience/resistance). This is the core concept behind **sustainable development**.

Sustainable development is development which meets the needs of the present without compromising the ability of future generations to meet their own needs (World Commission on Environment and Development, 1987).

Climate change will undoubtedly lead to more pressure on already volatile commodity prices and trading. The general consensus is that in many regions, especially those in the tropics, agricultural productivity will decrease and food shortages will increase (Section 3). Additionally, not only will climate potentially decrease the amount of land available for agricultural production but there will be increased competition for resources with other development needs, such as infrastructure. Food and commodity prices have risen, and are expected to increase further because of instability in production quality and quantity due to climate change impacts.

If LDCs are to adapt to climate change they need to develop resilience by reducing long term vulnerability. Intercropping and increasing biodiversity, using drought tolerant varieties, utilizing surrounding ecosystems and their services, implementing sustainable production, including integrated crop and pest management and targeted (or alternative) irrigation and fertilizer application, are just some immediate strategies that can be used. If such knowledge is applied through a regional or local land management scheme developed and supported by extensionists, then resilience will naturally be increased. With an increasing demand for food, a predicted decrease in food production and a subsequent increase in food shortages, famine and poverty, there appears to be no alternative to the short term policy of importing food. Food insecurity will only get worse under climate change, threatening many millions of people in developing countries. Policies promoting the diversification of production in terms of number of commodities grown are simple risk-spreading strategies that could enable short term adaptation to climate change.

Over the past 50 years, human activity has changed all ecosystems more rapidly and extensively than in any comparable period of time. The demand for ecosystem services (Box 2) grew significantly as the world population doubled to six billion people and the global economy increased more than six fold. To meet this growing economic and population demand, food production has increased by roughly 2.5 times and water use more than doubled.

Climate change will have a rapid and significant impact on the agricultural systems and the natural environment. Established production systems are becoming increasingly destabilized and environmental stress, particularly water stress, is growing in parallel with rising demand for food. It has been estimated that China will lose self-sufficiency in food production by 2030 due to climate change (Erda *et al.,* 2008). The drive towards a select few varieties and crop species results in genetic erosion. Such changes are great challenges to biodiversity, which is the raw material used by breeders to create new crop/livestock varieties that will be needed to safeguard food and agriculture for future generations as well as for maintaining a broad gene pool, ensuring ecosystem resilience and resistance (Box 2). Genetically modified crops whilst useful in management of some commodity crops, such as cotton, has been a driver for much biodiversity loss as farmers opt for the new varieties over the older varieties and traditional landraces disappear.

Climate is central to agricultural production. It follows that as climatic parameters change then so will agriculture. This paper reviews climate change before considering the impact of climate change on some aspects of agricultural production. Focus case studies provide additional analysis and synthesis for the main agricultural commodities within CABI member countries India and Ghana (particularly cocoa); other specific commodities include cotton (with a focus on Pakistan) and coffee. The final analysis identifies knowledge gaps.

2. Review of climate change impacts

Climate has changed many times in response to a variety of natural causes but the term 'climate change' usually refers to those changes that have been observed since the early 1900s and includes anthropogenic and natural drivers of climate. The main human influence on global climate is through emissions of greenhouse gases such as carbon dioxide (CO_2) and methane. At present, about 6.5 billion tonnes of CO_2 are emitted globally each year, mostly through burning fossil fuels. Changes in land use mean a further net annual emission of 1–2 billion tonnes of CO_2. Such increasing concentrations of greenhouse gases in the atmosphere since the industrial revolution have trapped more energy in the lower atmosphere, altering global climate.

The observed changes in global climate (Box 3) are due to a combination of both natural and anthropogenic causes. The Intergovernmental Panel on Climate Change (IPCC) concluded that the balance of evidence, from changes in global mean surface air temperature and from changes in geographical, seasonal and vertical patterns of atmospheric temperature, suggests a discernible human influence on global climate. There are uncertainties in key factors, including the magnitude and patterns of long term natural variability (IPCC, 2001). The latest IPCC projections suggest anthropogenic climate change is continuing at an alarming rate, with an average global warming by 2100 of up to 6.4°C (Box 3; Fig. 1; IPCC, 2007). These projections indicate that the warming would vary by region, and be accompanied by increases and decreases in precipitation. In addition, there would be changes in the variability of climate, and changes in the frequency and intensity of some extreme climate phenomena.

Already there is evidence indicating climate change impacts on physical and biological systems across the globe. Examples include glacial retreat and shrinkage, permafrost thawing, lengthening of growing seasons particularly at mid to high latitudes, poleward and altitudinal shifts in organism distribution and phenological shifts (e.g. earlier budburst). Generally, changes in biological and physical systems are in line with the expected change for directional climate change (Box 4; 5). The probability that the observed changes in the expected direction (with no reference to magnitude) could occur by chance alone is negligible and there are high confidence levels that recent changes in temperature are having discernible impacts on physical and biological systems (Box 4; 5).

Climate change therefore threatens economic development in many countries but this effect may be of particular consequence in the tropical climatic zone where many LDCs are situated (Fig 1) and where climatic variability is already a significant challenge to poverty alleviation. It is essential that key indicators of the onset of climate change impacts are developed and monitored, with appropriate thresholds set to establish not only when action should take place but what type of strategy should be adopted. Considering the Millennium Development Goals as a framework on which to base indicators (http://mdgs.un.org/unsd/mdg/Default.aspx; United Nations, 2008), LDCs in the tropical zone require help in developing appropriate indicators, such as measures of poverty reduction, economic development, sustainability, ecosystem impact and status of threatened species, and reform of trade and investment policies. The impacts of climate change on agricultural production are considered further in Section 3.

However, agriculture and food distribution also affect climate change, principally through the production and release of greenhouse gases such as CO_2, methane and nitrous oxide (approximately 18% of the UK greenhouse gas emissions come from industrial agriculture and the food distribution system) but also by altering land cover, which changes the absorption or reflectance of heat and light, thus contributing to radiative forcing (a key process of the greenhouse effect). Deforestation and desertification, together with fossil fuel use, are major anthropogenic sources of CO_2; agriculture itself is a major contributor to increasing atmospheric methane and nitrous oxide concentrations. Agriculture energy use (producing CO_2) includes the storage, drying, cooling and processing of food crops, the production of fertilizers and other agricultural inputs as well as feed concentrates and the need for intensive grazing pasture. Livestock and manure produce methane, a potent greenhouse gas. Greenhouse and indoor livestock production are also energy intensive.

Box 3: Observed and projected climate changes

Observed

- Global average surface temperature increased over the 20th Century by 0.74 ±0.18°C
- Eleven of the last 12 years (1995–2006) rank among the 12 warmest years since instrumental records began (1850)
- In the past 50 years, cold days, cold nights and frosts have become less frequent while hot days, hot nights and heat waves have become more frequent
- Snow and ice extent, including mountain glaciers and snow cover, have decreased, consistent with the warming pattern
- The area affected by drought has increased since the 1970s
- Precipitation has increased in eastern parts of North and South America, northern Europe and northern and central Asia but has declined in the Sahel, the Mediterranean, southern Africa and parts of southern Asia

Predicted

- For the next two decades there is likely to be warming of 0.2°C per decade
- The projected rate of warming is greater than any observed during the 20th Century
- Global average surface warming will increase by 1.1–6.4°C by 2100 relative to 1980–99
- Global average water vapour concentration and precipitation will increase during the 21st Century
- Global mean sea level will rise by 18–59 cm between 1990 and 2100
- There will be an increase in Asian summer monsoon precipitation variability.

(Source: IPCC, 2007)

The consequences of climate change are far reaching and will affect all sectors of society. The more that is learnt about climate change impacts, the more complicated the issue becomes, but we have attempted to summarize the likely impacts of climate change on agricultural production in the next section.

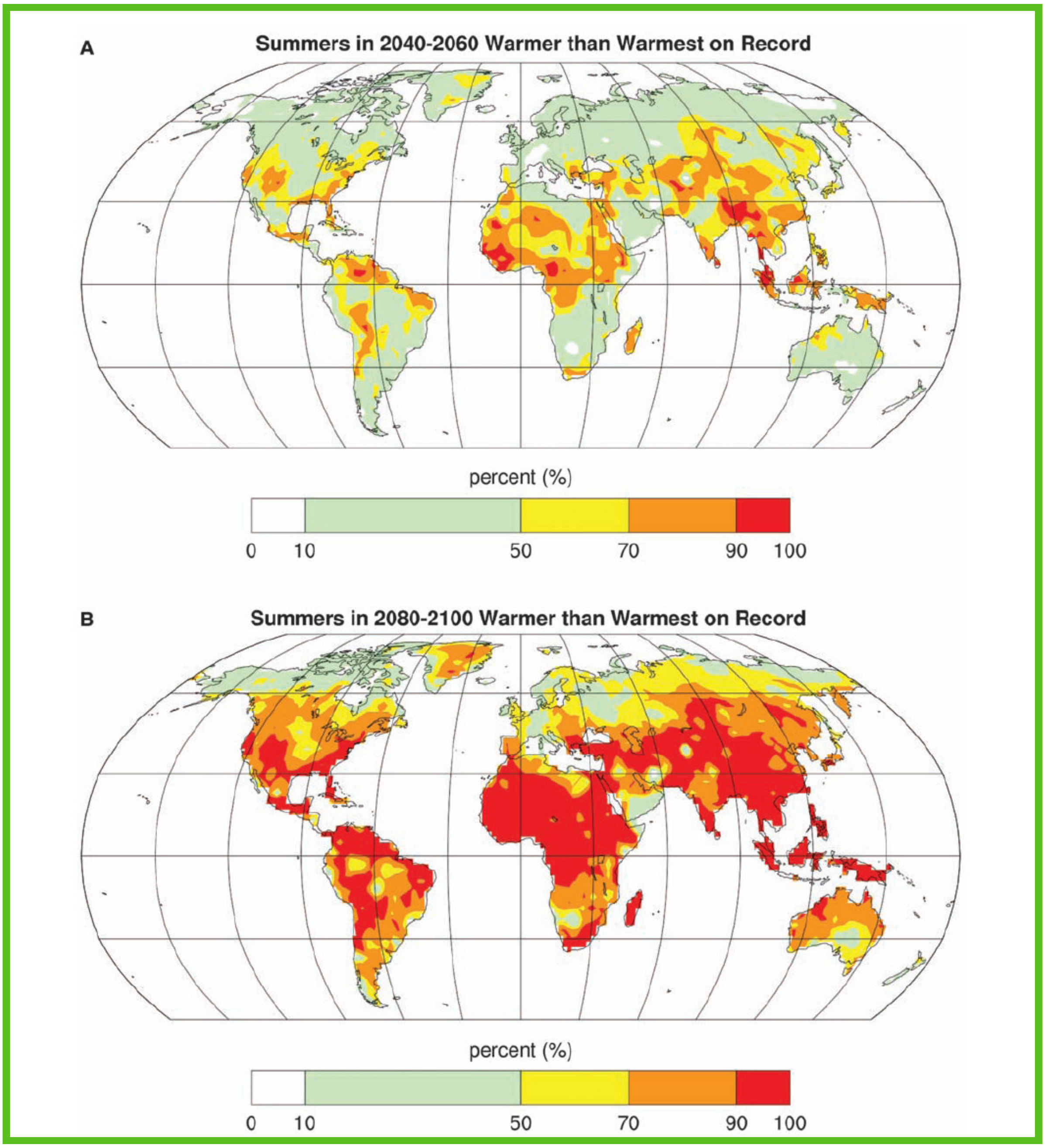

Fig. 1 Probability that projected average summer temperatures for (A) 2040–60 and (B) 2080–2100 will be greater than the highest temperature recorded (1900–2006). The areas shown in red have a greater than 90% probability that the future average summer temperature will exceed the highest temperature on record. (*Reprinted with permission from Battisti & Naylor, 2009)*

Box 4: Climate change impacts based on projections to the mid–late 21st Century. These do not take into account any changes or developments in adaptive capacity. *(Source: IPCC, 2007)*

Phenomenon and direction of trend	Likelihood of future trends	Examples of major projected impacts by sector			
		Agriculture, forestry and ecosystems	**Water resources**	**Human health**	**Industry, environment and society**
Over most land areas; warmer and fewer cold days and nights; warmer and more frequent hot days and nights	Virtually certain	Increased yields in colder environments; decreased yields in warmer environments; increased insect outbreaks	Effects on water resources relying on snow melt; effects on some water supplies	Reduced human mortality from decreased cold exposure	Reduced energy demand for heating; increased demand for cooling; declining air quality in cities; reduced disruption to transport due to snow, ice; effects on winter tourism
Warm spells/heat waves. Frequency increases over most land areas	Very likely	Reduced yields in warmer regions due to heat stress; increased danger of wildfire	Increased water demand: water quality problems e.g. algal blooms	Increased risk of heat-related mortality, especially for the elderly, very young, chronically sick and socially-isolated	Reduction of quality of life for people in warm areas without appropriate housing; impacts on the elderly, very young and poor
Heavy precipitation events. Frequency increases over most land areas	Very likely	Damage to crops; soil erosion; inability to cultivate land due to water logging of soils	Adverse effects on surface and groundwater; contamination of water supply; water scarcity may be relieved	Increased risk of deaths, injuries and infectious, respiratory and skin diseases	Disruption of settlements, commerce, transport and societies due to flooding; pressure on rural and urban infrastructures; loss of property
Area affected by drought increases	Likely	Land degradation; lower yields; crop damage and failure; increased livestock death; increased risk of wildfire	More widespread water stress	Increased risk of food and water shortage; increased risk of malnutrition; increased risk of water- and food-borne diseases	Water shortages for settlements, industry and societies; reduced hydropower generation potential; potential for population migration
Intense tropical cyclone activity increases	Likely	Damage to crops; windthrow (up-rooting) of trees; damage to coral reefs	Power outages causing disruption of public water supply	Increased risk of deaths, injuries, water- and food-borne diseases; post-traumatic stress disorders	Disruption by flood and high winds; withdrawal of risk coverage in vulnerable areas by private insurers; potential for population migrations; loss of property
Increased incidence of extreme high sea level (excludes tsunamis)	Likely	Salinization of irrigation water, estuaries and freshwater systems	Decreased freshwater availability due to salt water intrusion	Increased risk of deaths and injuries by drowning in floods; migration related health effects	Costs of coastal protection vs costs of land-use relocation; potential for movement of populations and infrastructure; also see 'tropical cyclones' above

[1] based on projections for 21st Century using SRES (Special Report on Emissions Scenarios).

Box 5: Key impacts as a function of increasing global average temperature change

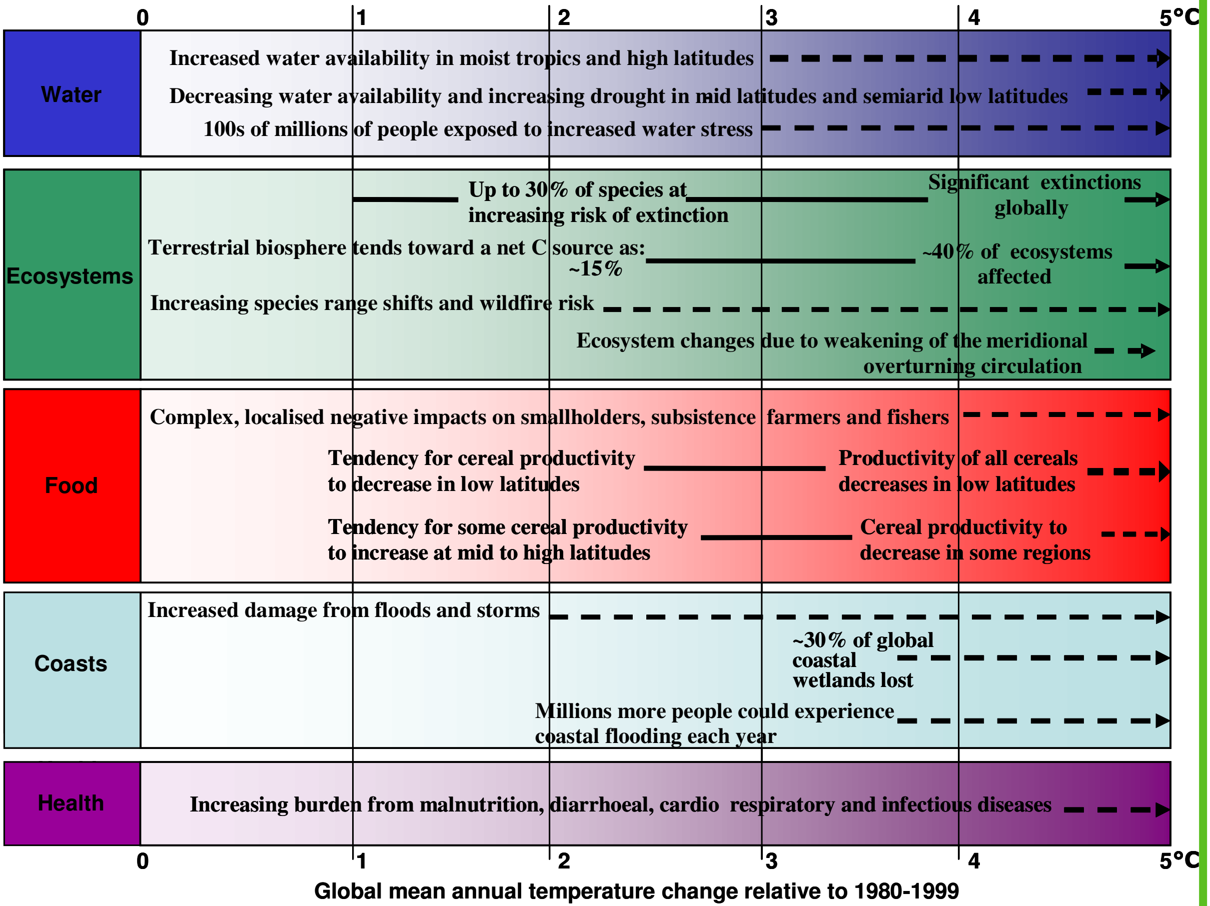

Illustration of global impacts projected by climate changes associated with different amounts of global average temperature increase in the 21st Century. The black lines link impacts; the dotted lines indicate impacts continuing with increasing temperature. Entries are placed so that the left hand side of the text indicates the approximate start of a given impact. All sectors, water, ecosystems (natural and managed), food, coasts and health, will be compromised and changed due to climate change. The impacts illustrated are those with the greatest links, either as a driver or as a consequence, to agricultural production. For example, there is widespread malnutrition projected but agricultural production will be further compromised, the ecosystems around cereal fields will experience changes in structure and function thus compromising functional biodiversity and the ability of farmers to use natural control strategies to deal with pests and water shortages are likely. Hence, increased food production to counter malnutrition is unlikely unless novel adaptation strategies are developed and implemented urgently. Adaptation to climate change is not included in these estimations. All entries are from published studies recorded in the chapters of the IPCC Working Group II Assessment. *(Source: modified from IPCC, 2007).*

3. Climate change impacts on agricultural production

Climate change will impact on agricultural commodity production globally due to the effects on plant growth and yield from elevated CO_2, higher temperatures, altered precipitation and transpiration regimes, and increased frequency of extreme events, as well as modified weed, pest and pathogen pressure.

Although the current green revolution in agricultural production has led to many technological advances such as improved varieties, GMOs (genetically modified organisms), physiological improvement, seed treatment, targeted irrigation and fertilizer applications and integrated pest management (IPM), the local climate is still the greatest factor in determining how much food is produced in a given region or locality (Fig. 2). Even with these man-made improvements, temperature and precipitation relations are major factors in determining where a crop can grow, whether there is any yield, how many crops can be grown per year and what type of crop can be grown in a certain location. Seed viability, germination and plant growth, development, stature, phenology, fruiting and seed mass are all governed by temperature, water (precipitation/soil moisture) and the interaction between these two climatic factors. Indeed, a 'healthy' plant, which has just the right ratio of temperature and water for its optimum development, is generally more resistant to attack by pests and diseases (conversely, stressed plants are more susceptible to attack). Crop growth models, used by agriculturists and agronomists, are climate dependent and so increasingly are being linked or incorporated into climate change models and general circulation models (GCMs).

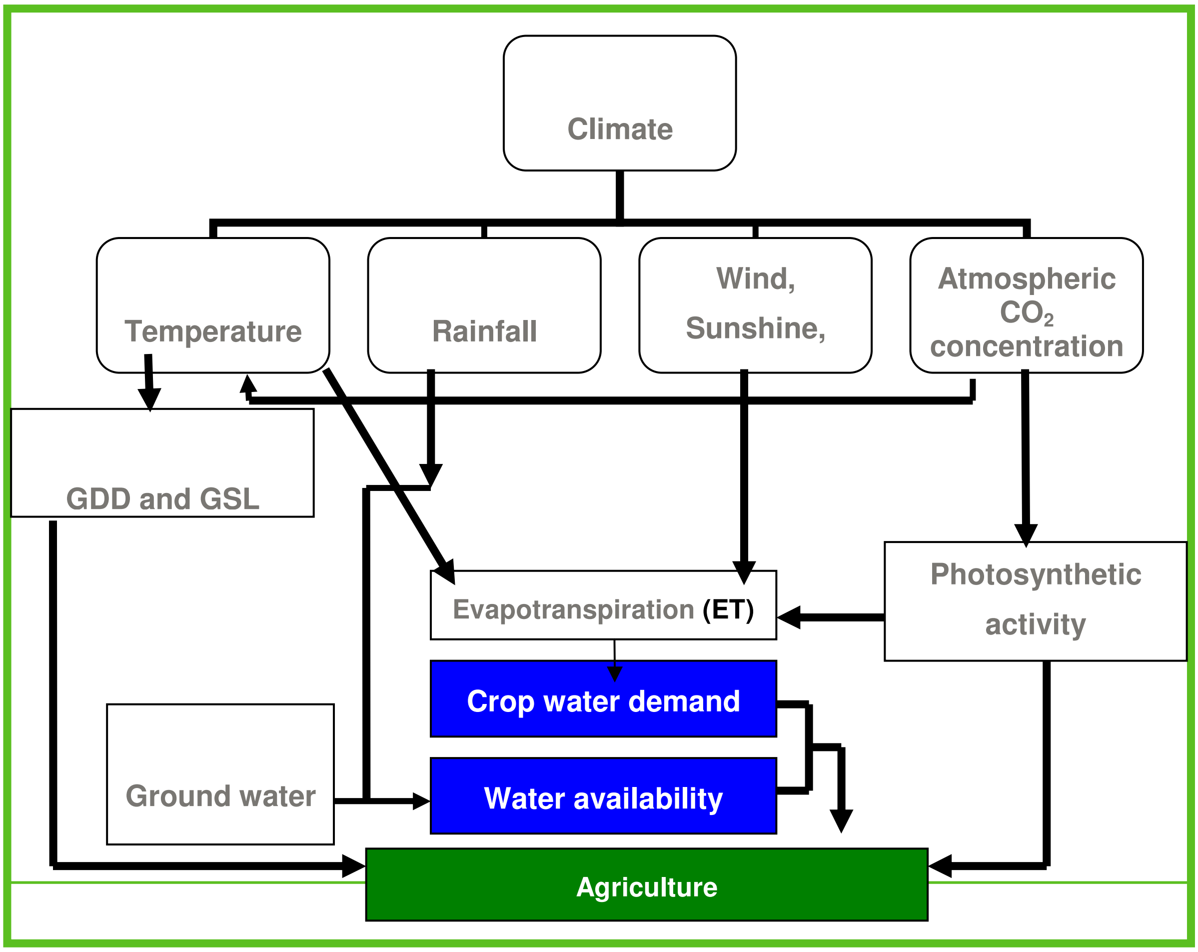

Fig. 2: The impact of climate on water availability and then their combined impact on agriculture (crop yield). GDD: growing degree days; GSL: growth season length. (Adapted from M.A. Goheer, Global Change Impact Studies Centre (GCISC), Pakistan)

Such relations underlie the susceptibility of agricultural production to climate change (Fig. 2). Climate is the prime driver of agricultural production and thus climate change will have a significant impact on agricultural commodities. This impact is projected to be positive and negative, depending on the severity of the climatic changes, and the agricultural system, locality and capacity to adapt. In recent decades, international trade in agricultural commodities has grown rapidly, and so in addition to climate change affecting agriculture locally or at the regional scale, the impact of climate change on a global scale has to be considered. Certain crops are favoured by trade, to the extent that over 70% of the world's food comes from just nine crops (rice, wheat, maize, oats, potato, barley, cassava, soybean, sugarcane), each of which is now cultivated far beyond the native range to maximize income.

Farmers everywhere naturally manage their systems for climatic variability. Climate change, though, will have a sustained and increasing impact on agricultural systems, through increasing temperature, increasing greenhouse gases, and, probably most importantly, increasing variability in frequency and severity of climatic events, particularly extreme weather events. Farmers generally use historic records to aid in planning what, when and where to plant or graze, but without accurate, reliable regional forecasts of climate change they are likely to experience greater pressure on production, as timing, location and crop choice are likely to be wrong or at least suboptimal. In many places, growing seasons are changing, ecological niches are shifting, and rainfall is becoming more unpredictable and unreliable in both its timing and its volume (rainfall projection; Fig. 3). This is leading to greater uncertainty and heightened risks for farmers, and potentially eroding the value of traditional agricultural knowledge such as when to plant particular crops. Accurate predictions are essential to developing adaptation strategies (e.g. introducing a new crop more suited to the future climate) and implementing mitigation strategies if there is time to do so.

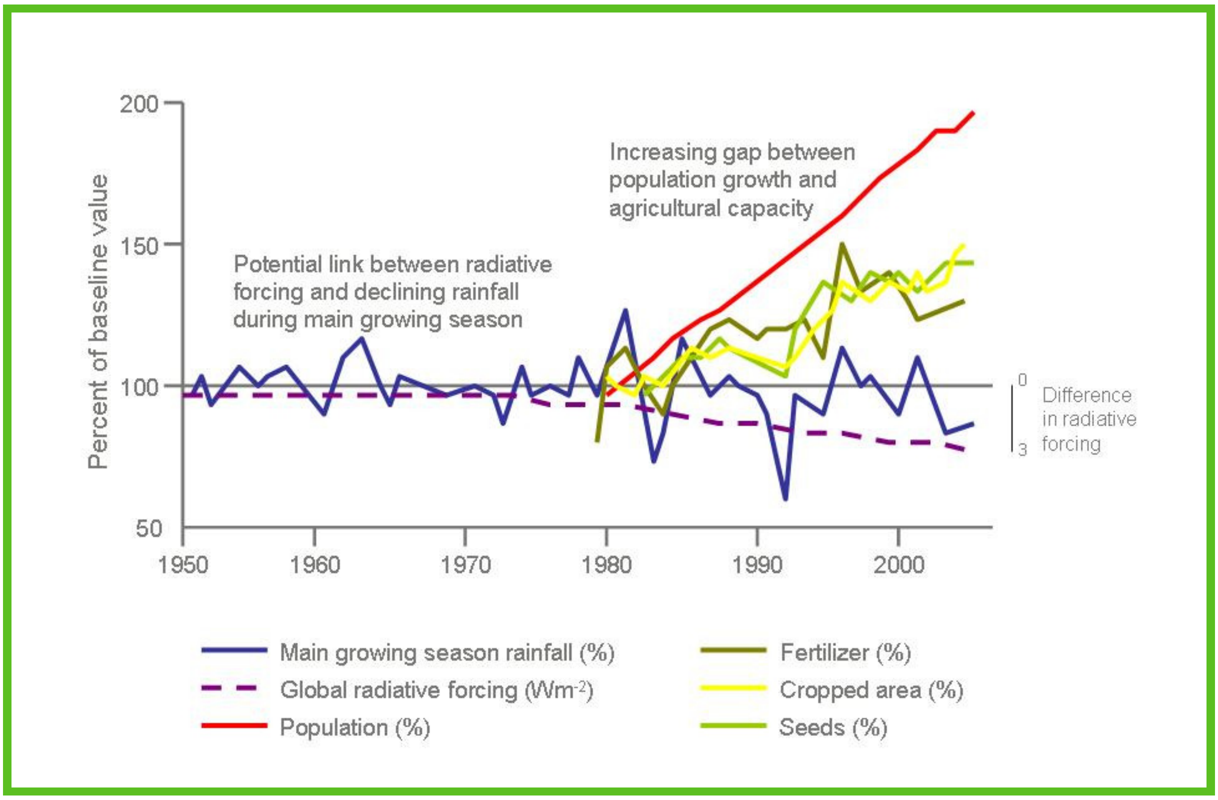

Fig. 3; Agriculture and rainfall tendencies for eastern and southern Africa: food security analysis – rainfall, population, cropped area, seed use and fertilizer use. Rainfall is shown as the percentage of the 30-year average for 1951–80. Other variables are expressed as percentages of averages for 1979–81. Global radiative forcing is shown by the broken line. (*Adapted from Funk et al. 2008; data originally from the Food and Agriculture Organization of the United Nations; FAO)*

Climate change will have a range of impacts on agricultural systems and production (Fig. 4; Fig. 5). It is likely that the life cycle of crops will progress (advanced phenology) more rapidly; but with rising temperatures and variable rainfall, crops are expected to fail, especially if there is a decrease or increased variability in precipitation. However, the situation is more complicated; gains and losses are predicted for crop yields, depending on locality, crop type and production system (Fig. 4; Fig. 5). Global warming in the short term is likely to favour agricultural production in temperate regions (largely northern Europe, parts of North America) and negatively impact tropical crop production (South Asia, Africa), where the majority of LDCs are located. For example, southern Africa has been projected to lose over 30% of its maize yield by 2030 (Lobell *et al.,* 2008). Additionally, over 10% losses of important staple crops such as maize, rice and millet are projected for South Asia within the same time period. Even small changes in temperature and rainfall could have significant effects on the quality of cereals, fibre and beverage crops, fruits, and aromatic, and medicinal plants with resultant implications on their prices and trade.

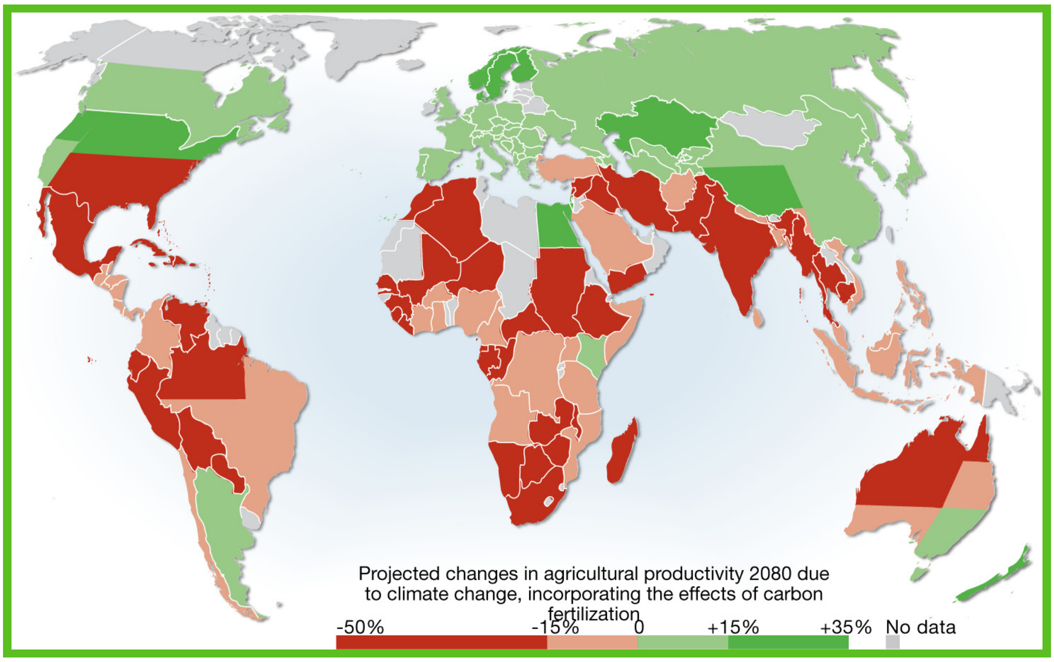

Fig. 4: Projected changes in global agricultural productivity by 2080 due to climate change (and carbon fertilization). Red areas indicate a decrease in productivity and green areas indicate an increase. Tropical areas are generally expected to have biggest decreases in agricultural production. (Graphic by Hugo Ahlenius, UNEP/GRID-Arendal, Projected agriculture in 2080 due to climate change, UNEP/GRID-Arendal Maps and Graphics Library, http://maps.grida.no/go/graphic/projected-agriculture-in-2080-due-to-climate-change)

The population of undernourished people in eastern and southern Africa has doubled in the last 25 years; often this increase has been coupled with the cessation of development in rural areas (including agricultural capacity) and rural poverty increasing in the last 10–15 years. During the same time period, this region and the LDCs/food insecure countries of the western rim of the Indian Ocean have been subjected to a 15% reduction in rain during the growing season. Such drought and the rural social disruption in food insecure countries are projected to lead to a 50% increase in the number of undernourished people by 2030. These relationships between rainfall, population, cultivated area, and seed and fertilizer use are shown in Fig. 3, which also shows how mitigating or adapting to one of these components may offset the effects of the others. For example, modest increases in per capita agricultural productivity could more than offset the observed precipitation declines. Consequently, investing in agricultural development can help mitigate climate change while decreasing rural poverty and vulnerability.

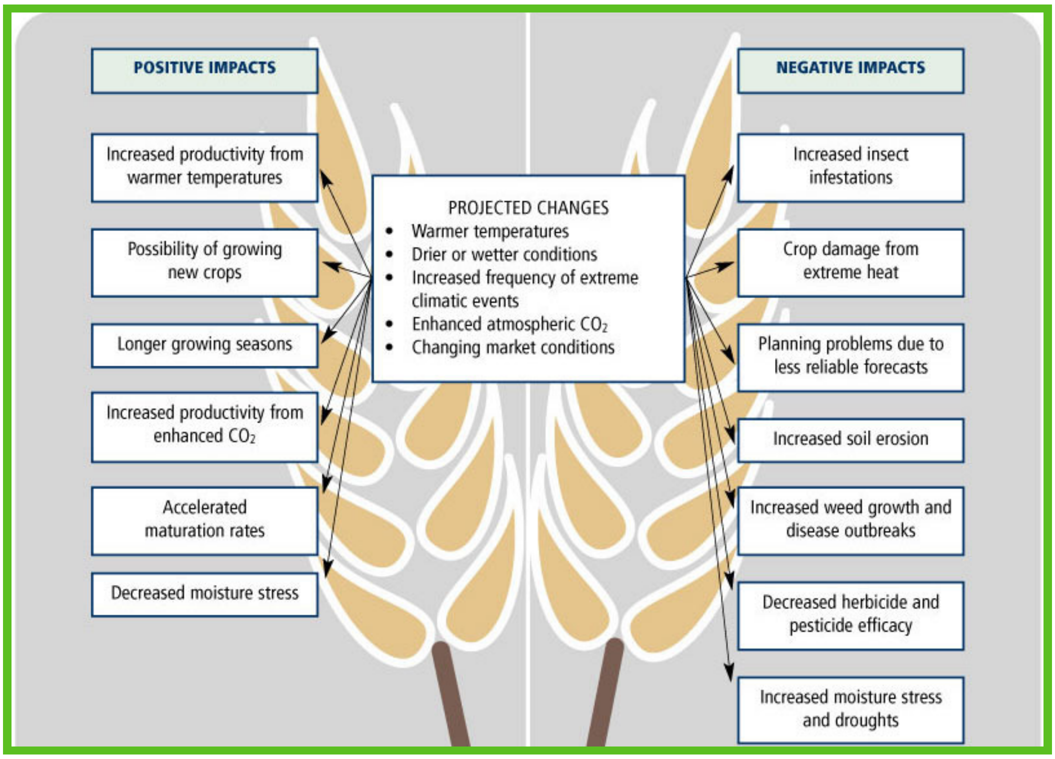

Fig. 5: Potential impacts of climate change on agricultural crops in Canada. Climate promoted invasive species impacts (pests, diseases and weeds) are expected to be increasingly detrimental. (From Climate Change Impacts and Adaptation: A Canadian Perspective: Agriculture www.adaptation.nrcan.gc.ca/perspective/summary_5_e.php. This reproduction is a copy of an official work that is published by the Government of Canada but it has not been produced in affiliation with, or with the endorsement of the Government of Canada).

Although general projections of the impacts of climate change are useful in some respects, they are subject to some uncertainty as the specific climate change model adopted for the analysis can have a significant effect on the outcome. Therefore, recently crop models have been integrated with General Circulation Models (GCMs for a range of increased CO_2 climate scenarios (Easterling *et al.,* 2007; Hansen, 2005; www.adaptation.nrcan.gc.ca/perspective/summary_5_e.php) in an attempt to remove these uncertainties and this approach is proving to give consistent projections. Such analyses indicate that understanding the water cycle and how it is affected by temperature, in particular, is key in terms of agricultural production.

Increased moisture stress and drought are major concerns for both irrigated and non-irrigated crops. If adequate water is not available, production declines and entire harvests can be lost. While climate change is expected to cause moisture patterns to shift, there is still considerable uncertainty concerning the magnitude and direction of such changes. Longer growing seasons and higher temperatures are expected to increase demand for water, as would changes in the frequency of drought. In Africa and Latin America many rainfed crops are near their maximum temperature tolerance, so that yields are likely to fall sharply for even small climate changes; falls in agricultural productivity of up to 30% over the 21st Century are projected (Easterling *et al.,* 2007). Water stress, increased temperature, and the impact of an increased incidence and abundance of new invasive pests, diseases and weeds are almost certainly major factors in the projected agricultural declines in the tropics (Fig. 5). Invasive insect, disease and weed pests are likely to benefit most from climate change, leading to increased pesticide and herbicide use or greater reductions in yield (Masters & Norgrove, 2010).

3.1. Effects of increasing temperatures

As a generality (Easterling *et al.,* 2007) global food production is projected to increase overall with increases in average (local) temperatures of 1–3°C, but if temperature rises are above 3°C then global food production will decrease.

Temperature is fundamental in determining crop quality, quantity and where it can be grown. Due to the nature of this fundamental relationship in biology and ecology (Fig. 2), any changes in temperature through climate change will have large impacts on crop (commodity) production.

All stages of crop development are sensitive to temperature. Development generally accelerates in a linear fashion within certain temperature boundaries (e.g. between 10°C and 30°C for wheat; see Box 6), but with extreme temperatures the relationship becomes non-linear and increasingly difficult to predict. Higher temperatures often lead to heat stress which can result in increasing sterility and lower overall productivity in crops. As temperature rises there is increased evaporation from plants and soils resulting in increased water requirements while lowering water availability, which cause further stress to the crop.

Chronic effects of warmer temperatures on crop growth and development are probably more important than extreme effects in projecting climate change impacts. Crop yields reflect the importance of season-long effects, where crops generally have a greater yield when the temperature is cooler during growth of the harvested component. The length of crop growth cycles are temperature dependent. Increased temperature leads to the time between sowing and harvesting being shorter (e.g. for maize it could be between one and four weeks shorter). This could be beneficial in terms of a greater number of cropping cycles, thus increasing yield over the course of a year. However, such a reduction in the duration of the crop cycle could lead to earlier senescence thus having an adverse effect on productivity. Additionally, a greater number of cropping cycles will lead to greater inputs, resulting in soil nutrient and moisture depletion, greater exposure (apparency) to pests and greater pressure on what might already be marginal land.

Temperate zones

In Europe, temperature increases will lead to a poleward migration of suitable cropping areas and a reduction in the growing period of determinate crops (e.g. cereals), but an increase for indeterminate crops (e.g. root crops). In northern Europe climate change (temperature change predominantly) is expected to have positive implications for agriculture, with the introduction of new crop species and varieties, higher crop production and expansion of suitable areas for crop cultivation. Disadvantages may be a greater risk from pests and diseases and so greater plant protection needs, an increased risk of nutrient leaching and turnover of soil organic matter. In southern areas of Europe, the disadvantages will predominate. The possible increase in water shortage and extreme weather events may cause lower harvestable yields, higher yield variability and a reduction in suitable areas for traditional crops. These effects may reinforce the current trends of intensification of agriculture in northern and western Europe and extensification in the Mediterranean and southeastern areas of Europe.

Mild warming is projected to result in initial increases in crop yields in some other temperate regions (Fig. 4). For example, as highlighted earlier, when crop models have been integrated with GCMs (multi factor climate projections) and applied to Canada it has been demonstrated that maize, sorghum, soybean and wheat yields are expected to increase by 20–124% under climate change, due to the projected temperature increases and increases in CO_2. Nevertheless, once temperature increases exceed 3°C, yields decline. Likewise, yields of sunflowers, potatoes, tobacco and sugarbeet will initially increase while peas, onions, tomatoes and cabbages will suffer a decrease in yields.

Increase in temperature will lengthen the effective growing season in areas where agricultural potential is currently limited by cold temperature stress. Thus, increased temperature will cause a poleward shift of the thermal limits to agriculture. This poleward shift will be especially important for crops such as rice that have tropical centres of origin and adaptation but are also grown in temperate latitudes during warm seasons. Global warming impact will be greater in the northern hemisphere than the southern because there is more high-latitude area cultivated in the northern hemisphere.

Box 6: Temperature relations for wheat grain

A number of laboratory studies conducted with a temperature range of 25–35°C have shown:

- Average mean grain weight declined 16% for each 5°C increase in temperature
- Average grain yield decreased by 17% for each 5°C rise in temperature
- Average grain yield decreased by 8–10% (through having 5–6% fewer grains combined with 3-4% smaller grain weight) for every 1°C rise in temperature

When the mechanism of reduced grain filling under higher temperatures was investigated, it was found:

- Photosynthesis had a broad temperature optimum from 20°C to 30°C but declined rapidly above 30°C
- Rate of assimilate movement out of the flag leaf (phloem loading) was optimum around 30°C
- Rate of assimilate movement through the stem was temperature independent from 1°C to 50°C
- Respiration effects did not result in decreased grain size with increasing temperature

Reduction of grain weight by heat stress may be explained mostly by effects of temperature on rate and duration of grain growth:

- When temperature was increased from 15/10°C (day/night) to 21/16°C, grain filling time reduced from 60 to 36 days and grain growth rate increased from 0.73 to 1.49 mg/grain/day (with a result of minimal influence on grain weight at maturity)
- When temperature was increased from 21/16°C (day/night) to 30/25°C, grain filling time reduced from 36 to 22 days with a minimal increase in grain growth rate from 1.49 to 1.51 mg/grain/day (resulting in mature grain weight being significantly reduced at the highest temperature)

So, in wheat, high temperatures reduce grain yields because of a reduced number of grains formed and a shorter grain growth time.

Source: Abrol & Ingram 1996.

In general, in temperate areas it is projected that warming will be greatest during the winter months but warmer winters are also expected to create problems for agriculture, especially with respect to pests as extreme winter cold is often critical for controlling populations.

Tropical zones

In the tropics, the situation is very different. Any increase in temperature is projected to cause crop yield decline, particularly for maize and rice (whose centres of origin are in or close to the tropics) as these crops are already near the upper limits for their optimum growth (Fig. 6). Indeed, areas where coffee is currently produced will generally get hotter leading to a contraction in the top quality areas and the lower limit of cultivation rising by 3–7 m every year. Overall there is likely to be less coffee produced and of poorer quality (Section 7).

In tropical regions, the impact of increased temperatures is generally projected to be less than that expected in temperate regions (IPCC, 2007) but is still sufficient to significantly reduce the length of the effective growing season, particularly where more than one crop per year is grown. In semi-arid regions and other ecozones where there is wide diurnal temperature variation, relatively small changes in mean annual temperature could markedly increase the frequency of highest temperature injury. For example, canopy temperature is 10–15°C higher in upland cotton (*Gossypium hirsutum*) than in irrigated cotton (Section 6).

Thus, global warming would reduce dry matter accumulation in dryland cotton because of increased respiration, and reduced photosynthesis and cellular energy.

Many crops in the tropics already experience heat stress. As temperatures increase due to climate change, crop failure in some traditional areas would become more commonplace. For example, crop growth models show that rice yields decrease 9% for each 1℃ increase in seasonal average temperature. This chronic effect of high temperature differs significantly from the acute effect of short term temperature events, because seasonal temperature effects are mostly a result of effects on crop development. For most grain crops, there is much greater genotypic variation in thermal requirements for vegetative than for reproductive development. As long term temperatures increase, grain filling periods decrease, and there appears to be little scope to manipulate this effect through existing genetic variation within species.

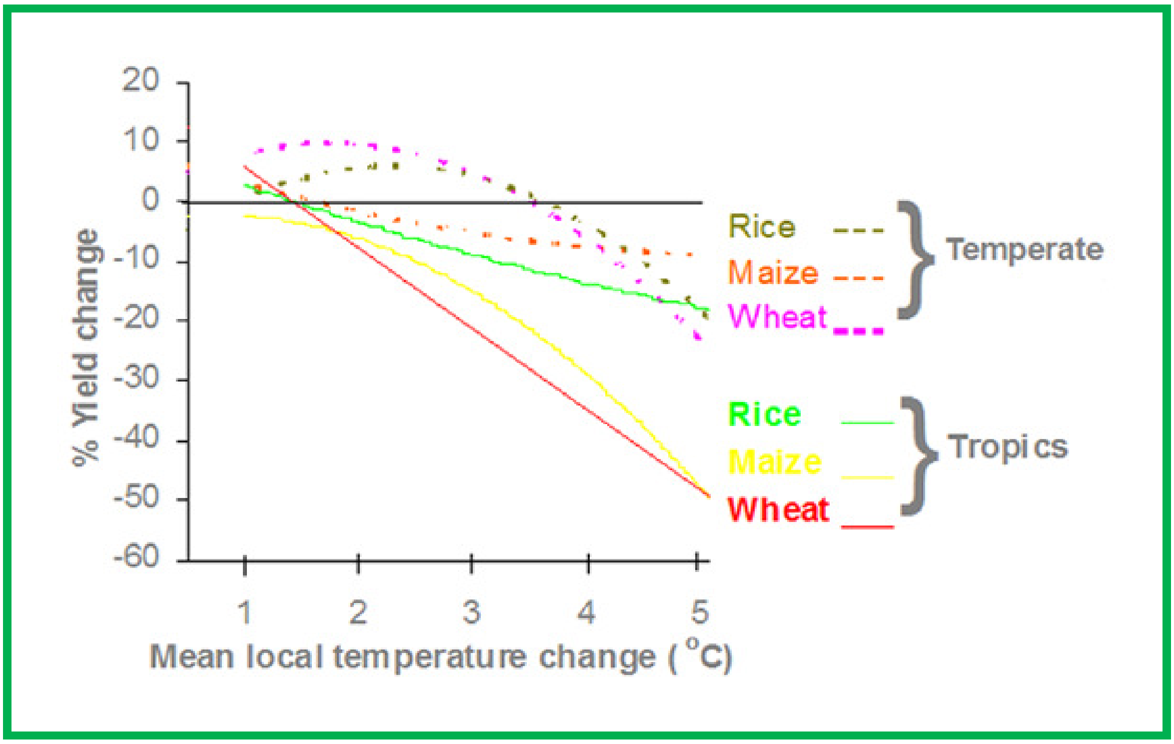

Fig. 6: Comparison of temperature rise on crop yields in temperate and tropical regions. (Adapted from IPCC, 2007 in Nicholls et al., 2008)

3.1 Changing precipitation patterns

Like temperature, precipitation and water availability is central to agriculture, with productivity being optimal at a particular water balance. If this is decreased (e.g. veering towards drought) or increased (towards saturation), then productivity will decrease. Although an increase in global average precipitation is projected (Box 3), this will be highly variable with certain regions experiencing prolonged droughts and/or extensive heavy rainfall. In the UK, for example, prolonged heavy rainfall during winter will be followed by periods of dry weather (drought) interspersed with intensive thunderstorms. Such changed precipitation patterns are expected to greatly impact agriculture, in terms of yield, distribution of crops across the landscape, opportunities for new crops and the expansion of marginal agricultural practices.

Agricultural productivity in tropical Asia is sensitive to changes in the nature and characteristics of the monsoon. Simulations of the impacts of climate change using crop models show that yield decreases due to climate change could have serious impacts on food security in this region. Climate change is likely to cause environmental and social stress in many of Asia's rangelands and drylands. In the arid and semi-arid tropics of Africa, which are already having difficulty coping with environmental stress, climate change resulting in increased frequencies of drought poses the greatest risk to agriculture. Impacts are related to projected temperature increases, the possible consequences to water balance of the combination of enhanced temperatures and changes in precipitation and sensitivity of different crops/cropping systems to projected changes. In Latin America, agriculture and water resources are most affected through the impact of extreme temperatures (excessive heat, frost) and the changes in rainfall (droughts, flooding).

Generally, increased precipitation would probably result in a greater risk of erosion, but could provide the soil with better hydration, depending on the intensity of the rain. Soil erosion increases in regions with increased frequency and severity of rainfall, particularly in winter. Nutrient leaching may increase, but likewise salt levels in soil may increase due to drought. The interactions between climate change, water scarcity and declines in agricultural productivity could lead to regional tensions and even open conflict between states already struggling with inadequate water supplies due to rising populations and over-pumping of groundwater.

3.2 Effects of increasing atmospheric CO_2

Plant response to elevated CO_2 alone, without climate change, is positive and was reviewed extensively by the IPCC (Easterling *et al.,* 2007) among others. The effects of elevated CO_2 on plant growth and yield will depend on species, photosynthetic pathways(C3 and C4 plants have enzymatic differences for carbon fixation)growth stage and management regime, such as water and nitrogen applications. On average, across several species and under unstressed conditions, compared to current atmospheric CO_2 concentrations, crop yields increase at 550 p.p.m. CO_2 in the range of 10–20% for C3 crops (e.g. rice, wheat) and 0–10% for C4 crops (e.g. maize, sugarcane, sorghum). Observed increase of above-ground production in C3 pastures is about 10%.

Simulations of unstressed plant growth and yield response to elevated CO_2 in the main crop simulation models (e.g. CROPGRO, SIRIUS) are in line with recent experimental data, projecting crop yield increases of about 5–20% at 550 p.p.m. CO_2. The main crop and pasture models, CENTURY and EPIC, project above-ground biomass production increases in C3 species of about 15–20% at 550 p.p.m. CO_2, i.e. at the high end of observed values for crops, and higher than recent observations for pasture.

Importantly, plant physiologists and modellers recognize that the effects of elevated CO_2 measured in experimental settings and implemented in models may overestimate actual field- and farm-level responses, due to many limiting factors such as pests, weeds, competition for resources, soil, water and air quality, which are neither well understood at large scales, nor well implemented in models. Assessment studies should therefore include these factors where possible, while analytical capabilities need to be enhanced. It is recommended that yield projections use a range of CO_2 effects to better convey the associated uncertainty range.

Carbon dioxide is essential to plant growth. Rising CO_2 concentration in the atmosphere can have both positive and negative consequences. Elevated CO_2 increases the size and dry weight of most C3 plants and plant components. Relatively more photoassimilate is partitioned into structural components (stems and petioles) during vegetative development in order to support the light-harvesting apparatus (leaves). The harvest index tends to decrease with increasing CO_2 concentration and temperature. Selection of plants that could partition more photoassimilates to reproductive growth should be a goal for future research. As more is learned about the effects of anticipated climate changes on crops, more effort should be directed to exploring biological adaptations and management systems for reducing these impacts on agriculture and humanity.

3.3 Elevated CO_2, temperature and precipitation interactions

Temperature and precipitation changes in future decades will at least modify, if not limit, direct effects of elevated CO_2 on plants. High temperature during flowering may lower CO_2 effects by reducing grain number, size and quality. Increased temperatures may also reduce CO_2 effects indirectly, by increasing water demand. Rainfed wheat grown at 450 p.p.m. CO_2 demonstrated yield increases with temperature increases of up to 0.8℃, but yield declines with temperature increases beyond 1.5℃; additional irrigation was needed to counterbalance these negative effects (Easterling *et al.*, 2007). In pastures, elevated CO_2 together with increases in temperature, precipitation and nitrogen deposition resulted in increased primary production, with changes in species distribution and litter composition. Future CO_2 levels may favour C3 over C4 plants, yet the opposite is expected under associated temperature increases; the net effects remain uncertain.

Climate impacts on crops will be dependent on precipitation. Over 80% of total agricultural land, and almost all grazing land, is rainfed; changes in precipitation as projected by GCMs will affect both the direction and magnitude of the overall impacts. Changes in precipitation and thus evapotranspiration modify ecosystem structure and function, as shown for UK agricultural grasslands from field-based research led by CABI and partners (Grime *et al*., 2000; Masters *et al.,* 1998; Masters & Brown, 2001). Higher water-use efficiency and greater root densities in field systems under elevated CO_2 may alleviate drought but their large scale implications are not well understood.

3.4 More frequent and extreme weather events

Extreme climatic events such as drought, flooding, hail, hurricanes and tornados are all expected to increase in frequency and severity as a consequence of climate change, and all can reduce agricultural production. Projected increases in frequency and severity of extreme events (in addition to the projected impacts of average climate change) will have significant consequences for food production and food insecurity. At the worst, this can be the complete destruction of agricultural systems but is more likely to be a greater reduction in crop yields and livestock productivity beyond the impacts due to changes in mean climate variables alone. For example, there is an increased risk of crop losses in Bangladesh from increased flood frequency. In the USA, projected heavy precipitation will lead to excessive soil moisture causing production losses (a doubling has been estimated by 2030 to US$3 billion annually; Rosenzweig *et al*., 2002). Increased soil erosion and salinization have also been projected.

More frequent extreme events will reduce yields over the longer term by directly damaging crops at specific developmental stages, such as exceeding temperature thresholds during flowering, or by making the timing of field applications more difficult, thus reducing the efficiency of farm inputs. Climate variability and change also modify the risks of fires, and pest and pathogen outbreaks, with negative consequences for food production.

3.5 Changes in sea level

Obviously, changes in sea level will affect aquaculture (e.g. shrimps in the Indus Delta in Pakistan); rising seas will contaminate coastal freshwater aquifers with salt water, as experienced already by a number of island states. Such contamination of water quality will have knock-on effects on agricultural productivity. Higher seas also make communities more vulnerable to storm surges which can be 5–6 m high.

A rise in sea level will reduce the available land area for agriculture and this is particularly so for some CABI member countries in Asia; e.g. low lying areas of Bangladesh, India and Vietnam which will experience major loss of rice crops as sea levels rise. Vietnam relies heavily on the Mekong Delta for rice planting and a rise in sea level of up to one metre will submerge several square kilometre of rice paddies, rendering Vietnam incapable of producing its main staple and export rice crop.

In the following Sections, we illustrate some of these generic points regarding the impact of climate change on agricultural production through focussing on two CABI member countries and two commodities that CABI works on together with its member country partners.

4. CABI member country focus: India, agriculture and climate change

The impact of climate change is expected to be very high in India due to its dependence on agriculture, limited natural resources, rapid increases in human and livestock populations, changing patterns in land use and socio-economic factors that pose a great threat in meeting food, fibre, fuel and fodder requirements. There is a likelihood of a considerable impact on agricultural land use due to snow melt, availability of irrigation, frequency and intensity of inter- and intra-seasonal droughts and floods, soil organic transformation matters, soil erosion and availability of energy as a consequence of global warming, impacting on agricultural production and hence the nation's food security. Climate change is expected to impact on the

Source: http://www.state.gov/p/sca/ci/in/

hydrological cycle, namely precipitation, evapotranspiration, soil moisture etc., which would pose new challenges for agriculture.

4.1 Climate and future climate of India

Observations by the Indian Meteorology Department and the Indian Institute of Tropical Meteorology have confirmed the trends reported by the IPCC for India's climate (monsoon rain, temperature, heat waves, glacial melt, droughts and floods).

Monsoon. At the country level, there has been no consistent trend in monsoon rainfall during the last century, although there are some regional patterns. Areas with increasing monsoon rainfall are the west coast, north Andhra Pradesh and northwest India. Areas with decreasing monsoon rainfall are east Madhya Pradesh and adjoining areas, northeast India and parts of Gujarat and Kerala (–6 to –8% of normal over 100 years).

Temperature. A significant average warming of 0.4℃ has been recorded over the last century (1901–2000). A significant warming has been observed along the west coast, in central India and the interior peninsula and over north-east India. A cooling has been observed in the northwest and parts of southern India.

Drought, flood, storm, glacier. No significant long term trend in the frequency of droughts or floods has been recorded over the past 130 years. Additionally, the frequency of cyclonic storms forming over the Bay of Bengal over the period 1887–1997 has remained constant. However, there is evidence that Himalayan glaciers are melting and receding rapidly.

Projected climate change for all of India indicates that by 2100 there will be an increase of 15–30% in rainfall across the country and the mean annual temperature will increase by 3–6℃, with the maximum increase over northern India. The warming is also projected to be relatively greater in winter and post-monsoon seasons (Christensen *et al.,* 2007).

By 2050, the mean annual temperature is projected to increase by 2–4℃, and there are expected to be marginal changes in monsoon rain during the monsoon months but large changes during the non-monsoon months. The number of rain days is projected to decrease by over 15 days and rain intensity to increase by 1–4 mm/day, also with an increase in the frequency and intensity of cyclonic storms.

4.2 Impact of climate change on Indian agriculture

Agriculture represents a core part of the Indian economy, representing 35% of the GNP (gross national product) and thus is central in the country's development (in the last half century, grain production has quadrupled).

Increased temperatures as projected by the IPCC by 2100 are expected to lead to a 10–40% crop productivity loss overall. This is supported by work from the Indian Agricultural Research Institute which projects that for every 1℃ rise in temperature there is an associated loss of up to five million tonnes in wheat production, assuming irrigation continues at today's level (Aggarwal 2008). The loss in total farm net revenue expected is between 9% and 25% for a temperature rise of 2–3.5%. It is expected that a major impact of climate change will be on rainfed crops (other than rice/wheat) which contribute approximately 60% of the cropland area. Rainfed agriculture is practised by the poorest farmers.

Using historical records and crop-growth modelling, increasing temperature has been projected to have varying negative impacts on the yields of barley, chickpea, mustard and wheat in northwest India.

Wheat. Climate change will lead to changes regarding where in the country wheat can be grown profitably. A 2–3ºC increase in temperature will reduce yields in the majority of the wheat growing areas (Aggarwal & Sinha, 1993), and this yield reduction will be greater in non-irrigated (and thus water stressed) crops due to rainfall variability. So, the warmer regions will suffer crop losses. A minor increase of only 0.5ºC during the winter is expected to decrease wheat yield by 0.45 t/ha. However, as with most crops, the response of wheat yields is dependent on CO_2 fertilization, decreasing by up to 64% with no fertilization but ranging between +4 and –34% with CO_2 fertilization (Rao & Sinha, 1994). Climate projections indicate a continual decrease in wheat yield (Fig. 7).

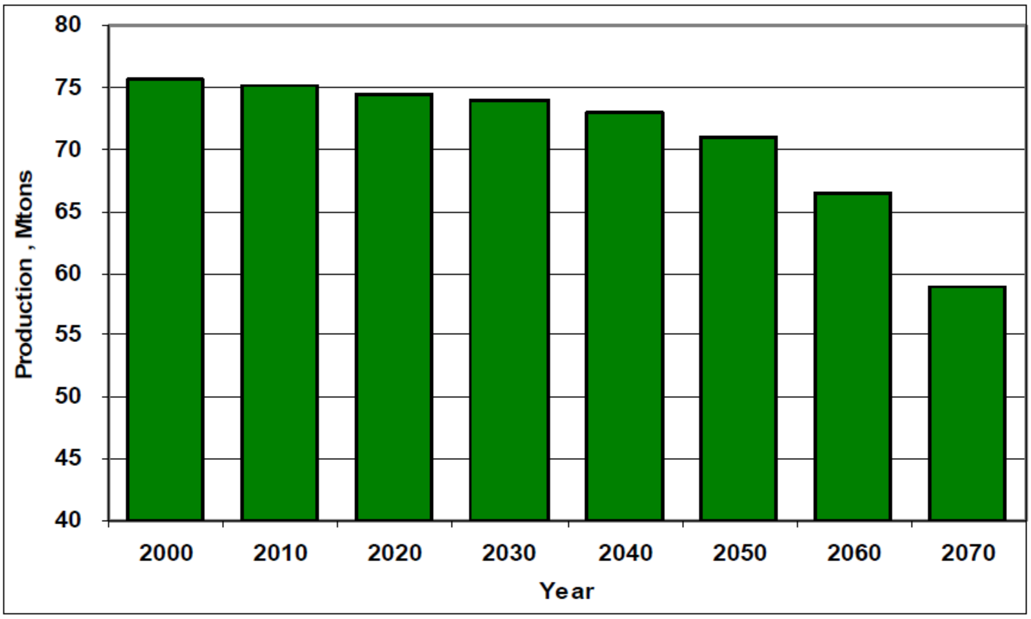

Fig. 7: Projected impact of climate change on wheat: production (total yield in million tonnes) estimates for India. *(Source: Aggarwal et al., 2002, as quoted in Chattopadhyay, 2008)*

The growing season for wheat is limited by high temperatures at sowing and maturation. As wheat is grown over a wide range of latitudes in India, it is frequently exposed to temperatures above the threshold for heat stress. For example, high maximum and minimum temperatures in September (about 34/20℃) adversely affect seedling establishment, accelerate early vegetative development, and reduce canopy cover, tillering, spike size and yield. High temperatures at the end of February (25/10℃) and during March (30/13℃) and April (30/20℃) reduce the number of viable florets and the duration of grain filling. The situation is similar for sorghum and pearl millet which are exposed to extreme high temperatures in Rajasthan (Abrol & Ingram, 1996; Abrol *et al.,* 1991).

Rice: An increase in temperature of 2–4ºC is expected to reduce yields. An increase of 2℃ may decrease the rice yield by 0.75 t/ha in high yield areas (Sinha & Swaminathan, 1991). Further work projects that a 1℃ rise will decrease rice yields by about 6%. There are, though, regional impacts, with eastern regions suffering the greatest impact with increased temperature and decreased sunshine leading to fewer grains and shorter grain filling time. However, northern regions will not suffer a net reduction in yield because lesser increases in temperature are offset by higher incidence of sunshine. The beneficial effect of CO_2 will be cancelled out by the negative effects of greater temperatures.

4.3 Implications of climate change impacts on Indian agriculture

Without doubt, increasing climatic variability (droughts, floods, tropical cyclones, heavy precipitation, extreme heat and heat waves) in the future will lead to large fluctuations (annual/seasonal) in agricultural production, resulting in increased risk of food insecurity issues, and thus will affect rural livelihoods throughout India.

Food security. Changing crop yields (increasing in some areas and decreasing in others), combined with a redistribution of which areas/regions can support growth, development and adequate yields of which crops, will directly impact consistency, quality and quantity of food supply, and thus create a bigger food security issue.

Trade. It is highly likely that imports and exports of commodity crops will be affected and this is particularly important for cash crops (e.g. chillies, coffee, tea, cotton, mango, grapes).

Livelihoods. Any changes in crop yield and distribution will affect livelihoods, particularly if yields decrease and the main crops in a region become marginal (or impossible) to grow due to climate change. Capacity building and education/training will be needed to cope with the new agricultural landscape.

Adaptation. Measures will need to be introduced to meet the changes imposed by climate change on agriculture on India; for example, alternative crops, new cropping patterns, water conservation, new irrigation technology and capacity building will all have to be researched and implemented as part of an adaptation strategy. Farmers and other stakeholders can begin to adapt, to a limited extent, to reduce agricultural losses. Simple adaptations such as changing sowing/planting dates and using new crop varieties could help in reducing impacts of climate change to some extent in the immediate future. The Indian Agricultural Research Institute estimate that losses in wheat production in the near future could be reduced from 4–5 million tonnes to 1–2 million tonnes if the majority of farmers could change to more timely targeted planting and to using better adapted varieties. These changes would, however, need to be examined from a cropping systems perspective.

4.4 What is CABI doing?

With partners, CABI is implementing a project investigating the resilience of coffee production to coffee leaf rust and other diseases. Climate change is an important component as it will lead to warmer and more variable conditions in many areas, meaning that coffee varieties will be under increased stress in future years. This will raise many urgent issues, including the conservation of coffee genetic resources and the continued productivity of the smallholder coffee sector. The effects of climate change on the genetic resources of countries make it necessary to review policies and practices to ensure that these resources are not eroded and that any new genetic material obtained is well conserved. The outputs of the project will lead directly to the uptake by farmers of appropriate varieties, growing techniques and methods for farm adaptation and control of diseases. Valuable data will be shared on the combinations of tree stock and growing style that work best under different conditions, which can then be more widely replicated. The intention is that the concept of long term participatory trials promoted by the project will continue long after the project is finished.

5. CABI member country focus: Ghana, agriculture and climate change

Source: http://www.state.gov/r/pa/ei/bgn/2860.htm

The Human Development Index of 177 countries ranks Ghana at 138, meaning that, overall, approximately 40% of the population is considered to be poverty stricken. Poverty levels are highest in the north where drought/desertification are dominant and widespread, and about 88% of the population lives in poverty (World Health Organization, 2006). Ghana's GDP consists of agriculture (37%), services (38%) and industry (25%). Major agricultural products include cocoa, rice, coffee and timber, of which cocoa and timber are exported (Dazé, 2007).

Land degradation is an increasing national problem. Desertification affects over 35% of Ghana's total land area, with the north-eastern region being at greatest risk. Unsustainable land uses, combined with natural vulnerability from the climate are the prime drivers of desertification. Greater incidence of drought in the future will add to this vulnerability. Soil degradation is caused by erosion, nutrient leaching and increasing salinity. The northern savannah is highly vulnerable to soil erosion, and the situation is projected to worsen due to heavy rainfall/storms as a consequence of climate change. Unsustainable cultivation, deforestation, overgrazing, fire and population pressures all contribute to the depletion of nutrients. Combined with the impact of climate change, reduced soil productivity will make sustainable subsistence agriculture-based livelihoods almost impossible.

5.1 Climate and future climate of Ghana

Over the last 30 years, climatic data shows that there has been a 1°C increase in average temperature, a 20% decrease in precipitation and a 30% decrease in runoff. Future projections of climate change indicate that Ghana will experience a 2.5–3.2°C increase in average temperature and annual rainfall will decrease by 9–27% (the relatively large range is principally due to spatial variation) by 2100. This historical data from the last 30 years also shows an annual sea level rise of 2.1 mm. By 2100, the sea level could have risen by 1 m resulting in coastal inundation, coastal erosion, saltwater intrusion into freshwater sources and a possible increased earthquake risk due to liquefaction (Amponsah, 2004; Boko *et al.,* 2007; Dazé, 2007).

5.2 Impact of climate change on Ghanaian agriculture

The agriculture sector employs over 60% of the workforce and is largely based on smallholdings (over 85% are 2 ha or less in size) and the majority of agriculture is rainfed. Cocoa is the principal cash crop, being grown on 40% of cultivated land. Cassava, yams and cocoyams are the most important root and tuber crops, which in total account for 40% of agricultural GDP (Dazé, 2007; CIA World Factbook, 2007; GINC, 2000). Millet is the staple crop in the savannah, and maize and rice are widely consumed throughout the country. Cereals are relatively vulnerable to climate change and are important in terms of food security. Ghana's high temperatures result in low cereal yields due to a limited growing period and high evapotranspiration (thus higher water requirements).

In the north of Ghana there is a high level of dependence on agriculture for livelihoods and the area is climatically sensitive with low and decreasing rainfall and frequent, recurring droughts, together making this the most vulnerable region to climate change. The dependence on rainfed agriculture across the country makes farmers in Ghana particularly vulnerable to climate change. Irrigation has recently been introduced but is not widespread. In 2000, only 0.5% of the cultivated area in Ghana was irrigated (AQUASTAT, cited in Dazé, 2007) but climate change will increase demand for irrigation water. Coupled with the reductions in rainfall and runoff as projected by climate models (Boko *et al.,* 2007), impacts on water availability for agriculture will be significant for this country.

Food crops. Cereals will be negatively affected by climate change. Increasingly variable rainfall will result in droughts, soil degradation and unpredictable growing seasons, all of which will reduce yields. Additionally, roots and tubers will be negatively impacted; cassava production is projected to decrease by 53% and cocoyam by 68% by 2080 (Anon, 2007; Dazé, 2007).

Cocoa. Cocoa accounts for 60–70% of foreign export earnings from agriculture or 20–25% of total foreign export earnings. Over 800,000 smallholder families (350,000 farm owners), mainly in the western region, depend on cocoa production for their livelihoods, as cocoa represents 70–100% of their household annual income. Cocoa farms are small, generally 0.4–4ha each – with a total cultivation area of 1.45 million hectares – and do not use technology or any significant inputs. Cocoa can only be profitably grown within a temperature range of 18–32°C and is susceptible to drought and the pattern of cropping is related to rainfall distribution (Anim-Kwapong & Frimpong [2006]; Dazé, 2007). Dry weather over four months results in a soil-water deficit leading to seedling mortality, reduced bean size and increased pest attack. . As a naturally occurring under-storey tree, cocoa is sensitive to high light intensities which can induce die-back of fine branches leading to attack by various pathogenic fungi and as more of the canopy becomes exposed to sunlight, the risk of further attack by mirids (already a very significant problem in Ghana) will increase. The plant is also highly sensitive to light, as prolonged exposure at high intensity disrupts photosynthesis but low light suppresses flowering. Given these climatic constraints, cocoa will be highly susceptible to climate change and this will have a large impact on the Ghanaian economy owing to the crop's pre-eminence as a foreign exchange earner.

Production of cocoa is projected to become increasingly difficult as climate change increases temperatures and leads to more erratic precipitation The geographic distribution of cocoa (and existing and new pests) will change, crop yields will decrease and there will be a greater incidence of crop loss, all of which will affect farm income, livelihoods and farm level decision making. A significant constraint to cocoa production currently in Ghana is that of aggressive black pod disease (*Phytophthora megakarya*) which can readily destroy a crop. As this pathogen thrives in humid conditions, any increases in precipitation or changes in rainfall patterns could have significant negative effects on the spread and impact of this disease. Its management currently relies on fungicide sprays (recommended eight times per year) so increased precipitation could mean more frequent spraying with associated environmental impacts.

5.3 Implications of climate change impacts on Ghanaian agriculture

Farmers need to develop and implement adaptation and mitigation strategies urgently. Simple strategies include the rehabilitation/restoration to sustainable production of degraded farms to reduce the effect of land degradation that encourages the adverse effects of climate change. Capacity building about the effects of climate change and how to deal with these changes needs to be urgently established.

Food security. Decreasing crop yields (in general) combined with a redistribution of which areas/regions can support growth, development and yield of specific crops, will directly impact consistency, quality and quantity of food supply, and thus create a bigger food security issue.

Trade. It is highly likely that imports and exports of commodity crops will be affected and this is particularly important for cocoa, Ghana's principle cash crop.

Livelihoods. Any change in crop yield and distribution will affect livelihoods, particularly if yields decrease and the main crops in a region become marginal (or impossible) to grow due to climate change. Ghana has an international reputation for producing cocoa of high quality and, as such, any climatic changes affecting quality would have large implications on trade and foreign exchange earnings. Currently, there are two production cycles for cocoa in Ghana and climate change could affect this; producers need to be made aware of likely impacts on their cash flow and prepare accordingly.

Adaptation. For cereals, adaptation strategies that could be implemented include the development or acquisition and use of drought tolerant varieties, use of early maturing genotypes, use of conservation agriculture as much as possible including low tillage, altered planting dates to suit changing cropping cycles and an increased use of irrigation. Cropping can be maximized, such that in the savannah zone, early millet, groundnuts and cowpeas are planted; and water conservation methods could be introduced for rice production. In the savannah–forest transition, maize could be replaced with sorghum or cowpeas and vegetable production diversified. In the forest zone, maize and cowpeas could be rotated. A similar approach to that for cereals could be adopted for root and tuber production, with improved or new capacity for better farm technology, new drought tolerant varieties, shifted sowing times, implementation of irrigation, improved postharvest technology and diversification of livelihoods.

A prime adaptation strategy for cocoa farmers is the implementation of drought management practices, including the exploration of irrigation, continuing use of shade trees and use of improved drought tolerant varieties. Socio-economic strategies such as secure land tenure, effective pricing and access to credit schemes would increase the capacity for farmers and other stakeholders in the supply chain to understand and adapt to climate change. Fortunately, as most of Ghana's cocoa is produced under shade, some of the worst effects of changes in light intensity could be mitigated but any cocoa cultivation occurring with little or no shade needs to have the impact of higher light intensities and temperatures on the crop taken into consideration.

5.4 What is CABI doing?

CABI has worked with the Cocoa Research Institute in Ghana (CRIG) for a number of years on various projects including examining alternatives to spraying pesticides to manage diseases such as aggressive black pod and most recently to help CRIG to survey pesticide use along the supply chain. Also with CRIG and Cadburys, CABI has pioneered the Ghana Cocoa Farmers Newspaper which could be a vehicle for introducing the concept of climatic change to cocoa farmers using cartoons and simplistic diagrams (www.cabi.org/files/newspaperposter.pdf).

CABI's work on irrigation and cotton (Section 6) can be applied to many areas where cotton is grown and water is limiting. In Ghana, irrigation of cotton in the north of the country could be a focus area for future work.

We now focus on two commodities, to give examples of CABI's work with cotton and coffee.

6. CABI commodity focus: cotton

Cotton (*Gossypium* species) is a leafy, green shrub, a member of the hibiscus family, producing natural fibre. Within the native ecosystem, cotton is a perennial growing to over 3 m in stature but commercially, cotton is grown as an annual. Cotton is the most widely produced natural fibre in the world and comprises over 40% of the global textile market. Cotton is highly dependent on water for growth; it takes 20,000 l of water to make 1 kg of cotton (which is enough for a single t-shirt and a single pair of jeans) and it is this water demand that makes cotton potentially susceptible to changes in climate. Places such as China, Pakistan and Central Asia, including India, are becoming increasingly water limited, but are also important cotton producing areas, so there is a potential conflict as water availability becomes increasingly limited.

6.1 Impacts of climate change on cotton

As discussed in Section 3, elevated CO_2 concentration in the atmosphere is projected to increase photosynthesis and water use efficiency in agricultural plants and thus increase growth and yield (a 40% increase in yield for cotton had been suggested). Yet, the situation is proving more complex, as the beneficial effects of increased CO_2 are expected to be offset by reduced rainfall, higher temperatures (heat stress) and their combined effect on evapotranspiration. Water limitation and temperature extremes will have detrimental effects on growth and development and these are expected to be greater than the growth promoting effects of increased CO_2.

Moderately increased temperatures could extend the cotton growing season and so have a positive effect on yield through an extended period for growth. Further positive impacts of increased temperatures could include improved crop establishment, reduced cold shock, and bigger plants with bigger leaves and longer fibres. However, this may be offset through an increased frequency of days/nights with high temperatures (heat stress) which has been found to have detrimental effects on growth and development, including reduced photosynthesis, high respiration, reduced flowering, reduced cotton boll development and short fibres.

The overall effect of climate change on cotton growth and development is, on balance, going to be detrimental. The negative effect of water limitation will be greater than the beneficial effects of moderate temperature and elevated CO_2 and so cotton yield is expected to decrease under climate change. Future climate change scenarios for the Mississippi Delta, USA, for example, estimate a 9% mean loss in fibre yield.

6.2 Pakistan, climate change and cotton

Pakistan already has most of its arable land under cultivation, and agriculture accounts for a quarter of the GDP and employs 50% of the workforce. The economy is highly dependent on trade in textiles (and the vagaries of that market), particularly cotton which generates significant export revenues but intensive cotton production is heavily dependent on water availability. Pakistan used to have a water surplus overall, which enabled such investment in cotton production but the climate of Pakistan is changing. Temperature extremes, heat waves and prolonged cold spells are becoming common. Extended droughts have reduced fresh water supplies, so highlighting the importance of adopting water conservation measures for the judicious use of this resource, especially in cotton production. Although irrigation in agriculture in general is not common in Pakistan, scheduled irrigation is widely practised in cotton production to the extent that overuse of irrigation water is very common and management of such scarce resources is required

Precipitation patterns are also changing; the frequency and intensity of extreme precipitation events has increased along the foothills of the Himalayas. Climate change, through increasing temperatures, will negatively affect the volume of freshwater storage in Himalayan glaciers and its slow release for crops in addition to changing the timing, duration and intensity of monsoon rainfall. In fact, the most significant climate change impact projected for Pakistan overall is increased variability in the monsoon rains. The volume of summer monsoon rains could increase by up to 60%, resulting in flooding and reducing fibre and food production, flattening crops such as cotton, and destroying irrigation systems.

This is exactly what has happened recently (2010) with severe flooding affecting 3 provinces namely Khyber Pakhtoonkhwa (NWFP), Punjab and Sind. The impact has been severe in all provinces but impacts have been different. In Khyber Pakhtoonkhwa, there has been a loss of infrastructure and teh sweeping away of land and crops along the river courses. In Punjab , three districts (Muzzafargarh, D.G. Khan, and Rajanpur) have been very badly affected as the flood waters from rivers have destroyed the irrigation systems. Standing crops (cotton, sugarcane, and fodder crops) and livestock have been destroyed as well as farmers' seed reserves such as wheat for planting for the next harvest. In Sind province, which is downstream from Punjab, the type of devastation is similar but has occurred on a much wider scale with about seven districts affected. Extensive losses in cotton production due to the floods has lead to unprecedented prices for cotton on the New York Stock Exchange (Cotton Futures) and in national markets e.g., in Lahore it has been reported that cotton is selling at 140 cents per pound (5th November 2010)

These climate driven changes will directly add to water, food and energy insecurity.

6.3 What is CABI doing?

CABI has investigated the impacts of cotton production on the freshwater ecosystem and identified good management practices to ensure sustainable cotton production with a minimum threat to this ecosystem. CABI empowered farming communities to identify and adopt sustainable cotton production technologies with long term benefits for water resources. This included elucidating the water requirements and water use patterns of the cotton plant. CABI integrated water saving techniques with other crop management techniques and developed plant water requirement monitoring criteria to assess when a cotton field should be irrigated. As climate change accelerates and water becomes scarcer in the cotton growing areas of Pakistan, then targeted irrigation with appropriate knowledge transfer will become increasingly important. Such knowledge transfer is a key strength of CABI, where there is considerable expertise in training different stakeholders along the cotton supply chain; integrating climate change into this capacity building will increase the ability of cotton producers and distributors to adapt to climate change (CABI Annual Review, 2008/2009; www.cabi.org).

Following the devastating floods in 2010, CABI has put its experience to use in the national recovery programme. The Project "Recovery of Agricultural Production in Flood-Damaged Communities in Muzaffargarh District, Punjab Province" will lead to the restoration of agricultural production for 7,000 households of the two tehsils (administrative units) of District Muzaffargarh, Punjab Province, most affected by the flood, through the rehabilitation of surface irrigation, the provision of tube wells for supplementary irrigation, extension services for crops and supply of inputs to re-establish crops.

7. CABI commodity focus: coffee

Coffee is a globally significant crop, grown in over 50 countries. Coffee exports are important foreign exchange earnings for producer countries and most coffee farmers are smallholders, who depend on coffee for a substantial proportion of their livelihoods. Coffee is suited to production on a small scale, as a family unit, as well as being appropriate for hillside farms where more demanding cash crops cannot be easily grown. The diversity of ways and environments in which this crop is grown means that the effects of climate change will be very diverse. Nevertheless, evidence of observed impacts of climate change on coffee production and the regions where coffee is grown is increasing CABI's work on coffee is geographically widespread, covering Latin America, parts of India, Africa and PNG.

7.1 Observed impacts of climate change on coffee

The climate has already changed in the coffee lands of Colombia; night-time minima have risen by 1°C over the last 50 years due principally to increased cloudiness. This increases pest pressure; for example the coffee berry borer (*Hypothenemus hampei*), which is resurging after control successes in the 1990s. Coffee is no longer grown below 1200 m in Colombia, principally due to the favourable conditions for this pest. Similarly, in 2007, Costa Rica lost 1.6% of its harvest to western leaf spot disease (*Mycena citricolor*) which surges in the increasingly intense rainy season that precedes the harvest period; similar losses were recorded in 2005 after Hurricane Stan – the losses sound small, but margins for most coffee producers are very slender and the pathogen attacks above 1400 m which is where the best coffee grows. Production has also been affected in Cuba where, in November 2007, the newspaper *Juventud Rebelde* reported a loss of 12% of the coffee harvest in the provinces of Granma and Santiago de Cuba due to extreme weather conditions. In Nicaragua in 2006, the poor rains, caused by an El Niño event, caused production levels to fall by up to 50%. These events are becoming increasingly frequent but the surprise was that this time it affected not only the traditionally drier area of Segovias, but also the normally wetter areas of Jinotega and Matagalpa. The cooperatives PRODECOOP and CECOCAFEN definitively attribute this decline in production to climate change and are anxious to develop strategies to confront it.

In Africa too, e.g. Uganda, many are starting to link coffee production problems to climate change (Box 7). In the mountains of Yemen, where some of the world's highest quality coffee grows, water extraction for irrigation is five times the quantity of precipitation. It is estimated that at current levels the region will dry up in a period of 20 years.

Box 7: Global warming threatens coffee collapse in Uganda

"Climate change has affected coffee production already," said Philip Gitao, executive director of the East African Fine Coffees Association. The crop has had less time to mature because rain is falling at the wrong times, affecting coffee quality, Gitao said. And there have been more droughts in the past two to three years than ever before. "If the coffee beans face a lot of sunshine and less rain, the beans will be smaller and in lower yields," Ronald Buule, a central Ugandan coffee farmer, said as he stood at a coffee plot bordered by lush plants, muddy hills, and an orange dirt road. "We are worried about the temperature, but we have limited resources," he added, as he examined his crops under a dense thicket of banana leaves.

(Alexis Okeowo in Nsangi, Uganda; from National Geographic News July 24, 2007)

In a world under increased threat from flood and drought, it would make sense to distribute production over many countries to reduce the risk of shortages, but the opposite is happening, with only seven countries responsible for three-quarters of world production; Vietnam now exports more than the whole of Africa (Fig. 8). Hence we are seeing increased land brought into production to grow coffee in a few countries and abandonment of coffee in others, even though coffee in the latter may be more environmentally and socially sustainable. Short term market considerations are sometimes moving the coffee further away from environmental sustainability, despite the actions of some commercial sustainable coffee schemes.

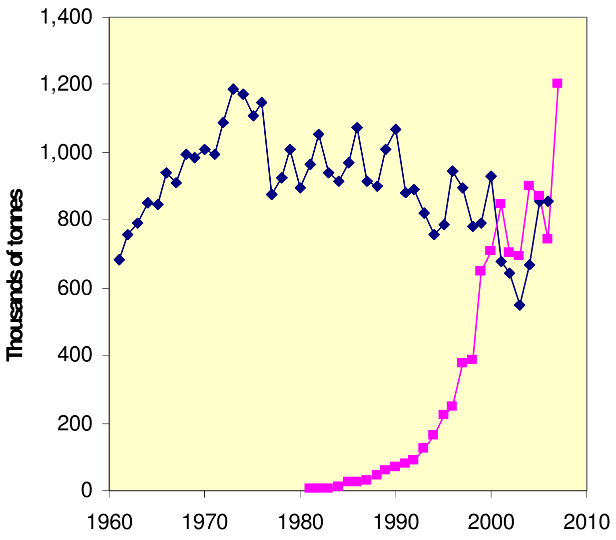

Fig. 8: Coffee exports for Africa and Vietnam. The amount of coffee exported from Africa (blue line) is variable between years, reflecting climate, markets and production, but shows a decline overall from the early 1970s. Coffee exports from Vietnam (magenta line) did not start until the early 1980s but have expanded exponentially since then, reflecting the land/forest clearance for coffee and investment in production. Vietnam is now a globally significant coffee producing country, exporting more that Africa. (*Source: FAOSTAT, http://faostat.fao.org/*)

No single example above can be proved to be directly caused by climate change, but the pattern of events is exceptional and wholly consistent with projections from models of climate change.

7.2 Impacts of climate change on coffee

For coffee production in Mexico, regression models have shown that rainfall in Veracruz between 1969–98 decreased by 40 mm annually and temperatures increased by 0.02℃ annually. Extrapolating these changes to 2020, coffee production would decline by 34%, reducing profits of US$495/ha, to less than $50/ha. Yield declines of Arabica are virtually certain in a warming world because it is a montane species, not adapted to high temperatures. Robusta as a high temperature alternative is not an option on the mountainsides because it is uncompetitive with mechanized production in Brazil. However, in Brazil, dramatic changes in production and revenue have been predicted from a physiological model by Pinto *et al.* (2005), who predicts yield declines due to increased flower abortion as mean annual temperatures exceed 23℃ (Box 8).

Box 8: Projected decline in production of coffee in São Paulo, Brazil

Increase in temperature	Area suitable for coffee (km^2)	Production (tonnes)	Change in production (tonnes)	Change in revenue (US$)
+1℃	145,202	269,082	–80,829	–113,160,600
+3℃	75,455	139,614	–210,297	–294,415,800

(Source: Pinto et al., 2005)

Quality would certainly be affected as mean temperatures rise, as the maturation process of the coffee cherry speeds up faster than the development of the bean, leading to lighter and lower quality berries. Also within coffee growing countries, zones where coffee is grown will change. A 3℃ rise in the 21st Century translates to the lower limit of coffee rising by 3–6 m per year. Production will shift in many cases, either putting pressure on other agricultural land or on biodiversity of virgin ecosystems.

For countries with fewer comparative advantages, sustainable diversification options are few, especially in those countries which have a significant industrial economy that leads to an uncompetitive labour price. Thus in Colombia the coffee lands are being converted to lower cost cattle pasture and even annual crops. Although this may make economic sense, externalities such as soil compaction, erosion and run-off mean that the ecological services provided by a perennial such as coffee are diminished.

7.3 What is CABI doing?

CABI's work on coffee with partners in Latin America, Africa, India, Indonesia and Papua New Guinea gives us many insights into how the industry will have to change to face the reality of climate change.

CABI's work on pests and diseases has found increasing signs that pests such as the coffee berry borer and diseases such as coffee leaf rust (*Hemileia vastatrix*) and American leaf spot (*Mycena citricolor*) are resurging. This is most likely due to more extreme weather events, for instance El Niño and hurricanes that provide conditions especially favourable to them – such occurrences used to be rare events but seem to be now more frequent. CABI's work with farmers will lead to more rapid updates on changing weather patterns, and assistance to carry out prompt prevention and control measures. Working with support institutes, CABI is providing the knowledge and capacity to be able to identify and react quickly to new pests and diseases that are likely to appear. Much of the information about climate change and coffee are highlighted in Baker & Haggar (2007).

Another focus area is biodiversity. For example, CABI and partners examined the biodiversity associated with coffee in Colombia, which even under such an intensive production system, harbours surprisingly high levels of biodiversity. Under climate change many species currently present in coffee are likely to disappear, but the patchwork of fields of coffee, forest, streams, gardens and plots of other crops will offer a refuge for species migrating upslope from warmer lower altitudes. Coffee too will decline at lower altitudes but it is clear that the landscape matrix that currently exists is capable of harbouring a wide range of biodiversity that will be greatly needed in the future for efficient ecosystem services, such as pollination and seed dispersal. Through participatory studies that CABI led, it was found that coffee farmers are very aware of environmental problems and are willing to adapt, as long as this does not affect their income. New trees and plants that can generate income and survive in changing conditions will have to be tested.

CABI has also pioneered farmer training schemes in Africa which have focussed on more environmentally friendly postharvest processing for coffee, so reducing water usage whilst allowing producers to obtain a premium for their coffee.

Recently, CABI has worked with the international coffee partners (Hamburg) to develop a Public–Private Project – the Coffee and Climate Change programme – to examine practical ways for farmers in four countries to adapt to and mitigate effects of climate change. This began in August 2010.

8. Summary and knowledge gaps

It is obvious that, in general, agricultural productivity will decrease, to a greater or lesser extent, under climate change, particularly with rising temperature and fluctuating extreme precipitation, i.e. increasing climatic variability. Consequently, food shortages and food insecurity will increase. LDCs with limited resources and little institutional capacity will be the least able to adapt to current and future changing climate, variable agricultural conditions, highly fluctuating agricultural commodity markets and increasingly frequent and severe food shortages. Also, many LDCs are particularly at risk due to their situation in the tropical zones that are projected to be most affected by climate change.

In areas of increased rainfall, more attention will be needed to reduce flooding and landslides and improve emergency responses. For all major crops, varieties that are more resistant to fungal diseases and pests will be needed as conditions will become more conducive for attack. There will be increased threats from new and different pests or diseases entering and becoming established in new regions or locales. In general, agricultural production technology and knowledge transfer needs revising and redesigning to make it efficient and sustainable to address the present and future threat of climate change.

8.1 Immediate research needs

There is an urgent need for more research and particularly action on adaptation measures in agriculture, especially in LDCs, to assist farmers, extensionists and supply chain stakeholders to reduce the adverse effects of climate change on agriculture. This is particularly so in the tropical zones, where LDCs are projected to be at great risk and often have large, resource-poor populations suffering from food insecurity.

The complex physical and biophysical impacts of the interactions between the different climate variables, combined with varying irrigation, fertilizer and pest and disease management strategies and techniques, regional variability (e.g. topography, soils, land use and management), and differences in crop growth, development, phenology, yield and resistance to drought and pests and diseases, mean that the detailed impacts of these factors need to be investigated further.

Specific recommendations for further research include:

- Increased precision in climate change projection with higher resolution on spatial and temporal scales;
- Linking projections with agricultural production systems to suggest suitable options for sustaining agricultural production;
- Preparation of a database on climate change impacts on agriculture;
- Evaluation of the impacts of climate change in selected locations.

In terms of experimentation, there is a lack of knowledge of responses to CO_2 and climate changes for the majority of crops other than cereal staples such as wheat, maize and rice, including many of importance to the rural poor (e.g. root crops, millet, brassicas). Some CABI partners are beginning to conduct important studies looking at climate change drivers and crops of relevance to individual countries. The Indian

Agricultural Research Institute, for example, has initiated elevated CO_2 FACE (Free Air Carbon-dioxide Enrichment) and temperature gradient polytunnel experiments to investigate cereal responses to projected climate change. CABI can partner these organizations and projects through our work on pest and disease management. The response of commodity pests and diseases to climate change is a knowledge gap and CABI's expertise and approach can address this research and implementation need.

In addition to the staples such as root crops and cereals, more work needs to be initiated on how climate change will impact on traded commodities such as coffee, cotton and cocoa and how changes in production area, yield, etc., will impact on the foreign exchange earnings of LDCs in particular – not least since until these countries' agricultural production is improved, their foreign exchange earners are important for funding the importation of food to maintain the very survival of the urban poor.

Much uncertainty remains regarding how changes in frequency and severity of extreme climate events, and climate change, will affect all sectors. Improved projection of future impacts of climate change requires better representation of climate variability at scales from the short term (including extreme events) to inter-annual and decadal. Where datasets exist (public/private) of climate and preferably yield, for 50 years or more, then there is an opportunity to conduct an analysis and project changes for the near future (the next 20 years). These projections should include, if possible, changes in mean, median, standard deviation and variance of temperature and rainfall, but also the distribution of wet spells and dry spells, absolute maxima and minima, and frequency of storms, frosts, and droughts. Valuable information can be gained to aid farmers in what to expect in the immediate future, for example dates of first and last frost, and variation in rainfall patterns. This approach will enable future climate information and forecasts and thus better management of crops and cropping systems. The projections can have climate change parameters built into them. CABI with member countries and partners can source datasets and run the analyses and projections. Results and conclusions could then be transferred to the agricultural stakeholders through appropriate means, for example the CABI Environmental Change Web Portal.

For all of these research priorities, arrangements should be made for the sharing of experiences and the transfer of good practices in agriculture that can constitute mitigation and adaptation, again a role for the CABI Environmental Change Web Portal.

8.2 Priorities

One immediate response, as acknowledged by the IPCC (2007; Easterling *et al.,* 2007), is to instigate capacity building to enable agricultural stakeholders to deal with climate change, but this development needs to focus on enabling agriculturists to respond to current climatic variability, thus providing the stepping stones to adapt to future, more extreme climatic variability.

CABI's country membership, combined with a depth of practical on-the-ground experience and extensive information and knowledge bases, puts us in a unique position to catalyse action by informing, updating and generally building capacity of countries, regions, communities and individuals (e.g. farmers, practitioners, extensionists, farmer groups, land managers) to take concerted action now to adapt to the new realities of the impacts of climate change. Action that CABI can lead and implement to tackle the issues, increasing problems and complexities agriculturists will face now and in the future include:

- Awareness raising and training on planning and zoning for donors and decision makers about the need for governments to take firm action to protect the fertile uplands of their countries. These resources will become ever more valuable as climate change forces upslope migration of flora, fauna and human communities. These territories are a country's primary asset and cultural heritage that should not be sacrificed to short term market goals. CABI has already undertaken a series of awareness raising lectures to donors and at commodity platforms such as the World Coffee Conference.
- Capacity building to reinvigorate institutions, including extension and research divisions. Presently, research is concentrated in a limited number of countries and institutions (e.g. prototype GM coffee varieties with drought resistance, delayed maturation and herbicide tolerance being developed and trialled in Brazil). In general, agriculture has stagnated in development over the last 30 years, although recently, perhaps in response to environmental change and the growing threat of food insecurity and starvation, there are signs of a new green revolution utilizing biotechnology (including varieties, agronomy and processing) and a greater understanding of ecosystem services, resistance and resilience, all central to sustainable development (Box 2). Without a more equal

approach to research, planning and active intervention, some countries will become ever less competitive. There is much to learn from Brazil's policies (Box 9).

- Adaptation planning and implementation. In the short to medium term there is much that can be done to help farmers adapt to climate change. In areas of increased drought, options and knowledge exist to start activities in water harvesting, improved irrigation technologies (e.g. drip irrigation, being used for coffee in Nicaragua), developing and use of drought resistant varieties, use of shade trees where appropriate, lean water use in processing, minimum tillage and many other technologies. There are many possible solutions that are not being developed, trialled nor implemented through lack of resources, knowledge and technology transfer, especially in LDCs.
- Coordinate efforts of governments, private organizations and other stakeholders in mitigating or adapting to the challenges of climate change.

Box 9: The lesson from Brazil – government intervention works

Agricultural losses in the 1990s were limiting the development of Brazilian agriculture. These losses were caused by two main factors:

- Excessive rain during the harvest period (30% of all cases)
- Dry spells during the flowering and grain-filling stages (60% of all cases)

These losses were related to a poor knowledge of rainfall distribution that led the farmers to plant at inappropriate times. To decrease risks, EMBRAPA (the National Institute for Agricultural Research) and the Brazilian Department of Agriculture started an official programme of agricultural zoning in 1996 to define planting calendars for rice, beans, maize, soybean, wheat, sorghum, cotton, coffee and fruits, based on a simulation of cumulative water balance.

Agricultural zoning is based on the integration of crop growth models, climate and soil databases, decision analysis techniques and geo-referencing. The planting calendars correspond to areas which produce more than 95% of Brazilian agribusiness GDP, which is about US$165 billion/year (total GDP: US$450 billion/year). The federal government has provided subsidiary support for agriculture since 1965. Funding levels were US$8 billion for the 2004/05 cropping season, with US$2.5 billion available for small farmers.

Agricultural zoning has been used as a federal farm credit policy since the rural lenders, mainly the Bank of Brazil, have had to use the planting calendars when supplying federal credit to farmers. This programme has helped farmers to use proper technologies, protect the soil and the environment, plan their activities, decrease their production costs and risks, and increase national production and productivity.

Brazil now has a global top-three position in production of ten commodities, including coffee, soya, sugar and maize.

(Adapted mostly from: Zullo et al., 2006)

8.3 Adaptation

The United Nations Framework Convention on Climate Change (UNFCCC) instigated National Adaptation Programmes of Action (NAPAs) to provide a process for LDCs to identify priority activities that respond to their urgent and immediate needs to adapt to climate change – those for which further delay would increase vulnerability and/or costs at a later stage. About 40 such action programmes now exist and need to be implemented. CABI has relevant expertise to offer in several areas relevant to commodities. Many NAPAs stress the need for introduction of new crops resistant to drought, which will require considerable upgrading of extension services and farmer training. Other urgent topics include reforestation, selection and growing of tree species in farmland, soil and water conservation techniques, promotion of agroforestry systems and home-garden agriculture.

Agricultural ministries and supply chain stakeholders need to design and implement adaptation strategies. Adaptation of land use and management, if adopted now, can mitigate (particularly in the short term) climate change impacts. Key strategies, which have largely been discussed previously, include:

- Use of new/improved varieties, crops or rotations (longer maturing varieties, heat- and drought-tolerant, requiring less vernalization). Alternatively, switching production from an increasingly unsuitable area to a climatic zone which is projected to be favourable for the commodity in the future;
- Designing and implementing irrigation and drainage systems;
- Adaptation to changed growing seasons or to a shift in timing of heat stress;
- Designing and implementing flexible cropping systems with mixed varieties, as trialled and implemented for commodities such as coffee;
- Improved use of sustainable technologies, including IPM, postharvest management and soil health, of which CABI has expertise and programmes.

In developing adaptation strategies, agriculturists and their stakeholders need to ensure they are not adding to climate change. Agriculture, particularly intensive production, produces approximately a quarter of global greenhouse emissions. Given predicted decreases in agricultural production and an increasing demand for food, there is an argument to intensify and expand to meet the demand. This is a real challenge as it needs to be balanced against the need to adapt to climate change and to attempt to stabilize greenhouse gas emissions.

Conserving and promoting ecosystem resistance and resilience has to be a central tenet of adaptation strategies and needs to be balanced with any actions to alter or intensify agricultural production.

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