NATURAL RESOURCES INSTITUTE

UNIVERSITY of GREENWICH

NRI Working Paper Series:
Climate Change, Agriculture and Natural Resources

No. 1

Climate Change, Agricultural Adaptation and Fairtrade

Identifying the Challenges and Opportunities

Climate Change, Agricultural Adaptation and Fairtrade

Identifying the Challenges and Opportunities

Valerie Nelson, John Morton, Tim Chancellor, Peter Burt and Barry Pound
Natural Resources Institute
University of Greenwich

May 2010

For further information please contact: v.j.nelson@gre.ac.uk
See **www.nri.org** for further details of our work and for other papers in this series

Contents

Executive summary

Climate change is projected, with high degrees of certainty, to have mainly negative impacts upon agricultural production, food security and economic development, especially in developing countries. It thus poses significant challenges for the Fairtrade movement. This report sets out what we know at present about those challenges and ways to face them, and makes recommendations for actions to build the resilience of farmers against climate change that can be followed within the avenues of impact of the Fairtrade movement.

Section 2 of the report introduces Fairtrade, and the avenues through which it seeks to achieve a positive impact for disadvantaged farmers and workers:

- Social development and environmental producer standards
- Trader standards
- Capacity building
- Networking, governance and advocacy.

It further introduces the key concepts of:

- Climate predictions and uncertainties
- Vulnerability to climate change as a social variable, as well as adaptive capacity, and resilience, the ability to cope with and recover from shocks and stress
- The importance of assessing stakeholder's' existing climate knowledge.

The complexity of likely impacts on smallholders is set out, combining impacts of extreme events, greater variability and changing means, each considered with respect to biological processes at crop level, environmental processes at landscape level, and impacts on human health and non-farm livelihoods. There will also be indirect impacts, of environmental processes elsewhere, and of the very policies introduced to deal with climate change, all to be considered within the context of the many other environmental, demographic, economic and policy trends affecting smallholders.

The literature on agricultural adaptation to climate change, and specifically the distinction between farm-level and institutional/policy adaptations is briefly reviewed. The important concept of agricultural innovation systems, including knowledge transfers between farmers and assorted stakeholders, and including social and institutional contexts for those transfers is introduced: innovations systems will need to be more decentralised and participatory to respond to climate change.

Section 3 summarises the main lines of scientific knowledge about climate change impacts on crops in general, and then reviews scientific literature relating to particular crops traded through Fairtrade systems, their known responses to changing temperature and precipitation, and projected impacts of climate change upon them. There are severe limitations in this literature, which tends to concentrate on cereal crops, does not distinguish Fairtrade commodities from conventionally traded crops, and can say little about the diversity of cropping systems around the world, but conclusions are set out here.

Rice

Increasing temperatures will lead to greater heat stress and an increased risk of spikelet sterility in rice. Rice is currently grown in some extremely hot environments and there is a large genetic pool for heat resistance which can be exploited by rice breeders. Nevertheless, it will take time before new varieties with suitable characteristics are available. Meanwhile, some projections suggest that increased temperature will lead to a significant reduction in the growing season for Basmati rice in the Indo-Gangetic plain and this will have an adverse effect on yield. In Mali, yields of summer rice may also be reduced due to higher temperatures. At present there is little Fairtrade rice produced in areas likely to be affected by increased coastal inundation so this may not have a large impact.

Cotton

The available evidence from experimental work conducted on cotton suggests that elevated levels of CO_2 are likely to favour increased canopy growth. Provided temperature is not limiting and adequate water is available, this enhanced growth will result in higher yields. Where average temperatures are above around 30^{0}C, yields are likely to decrease due to poorer fruit retention. Faster rates of plant growth will not necessarily lead to higher uptake of water. In central Asia, for example in Kyrgyzstan where Fairtrade cotton is grown, modifications to crop management practices may be needed to conserve water and reduce soil degradation in order to guarantee sustainable production. A change from surface furrow irrigation to sprinkler or drop irrigation greatly improves the efficiency of water use. The use of minimum and zero tillage practices can lead to a significant increase in cotton yield in wheat-cotton rotations when compared with conventional ploughing techniques.

Vegetables

In view of the wide variety of crops and production systems it is not possible to generalise the likely impacts of climate change on vegetable production. However, it is clear that for some crops such as tomato, eggplant and pepper the risk of adverse effects from exposure to heat stress will increase and this will have a negative impact on yields. In areas where there is a heavy reliance on supplementary irrigation greater variability in rainfall will affect production. For example, green beans grown in Kenya and Uganda require differing amounts of irrigation depending on the location and the rainfall pattern in a particular year. In some areas competing demands for water or the absence of an adequate water distribution system may make green bean production an increasingly marginal activity.

Coffee

In many coffee-growing regions a combination of lower rainfall and higher temperatures will render production unsustainable by 2050, at lower elevations where the crop is currently cultivated. Farmers will need to make more use of shade trees, select drought-resistant varieties and use supplementary irrigation. Higher altitudes, where it is currently too cold to grow coffee, will become more suitable but available land is usually scarce and the environment highly fragile.

Cocoa

The main threat to cocoa production posed by climate change lies in the increased susceptibility of trees to drought. This is a particular concern in West Africa where the adverse effects of high variability in seasonal rainfall patterns is already a constraint to cocoa yields.

Tea

As with coffee and cocoa, the probability of increased variability in rainfall will increase the vulnerability of tea plants to drought stress. In east Africa, tea production is likely to become less viable at the lower levels of its current altitudinal range within the next few decades. A reduction in quality is also likely to occur in some varieties as temperatures increase at higher altitudes.

Bananas

Changes in rainfall patterns are likely to have a larger effect on banana production than increases in temperature. In countries in Central and South America where Fairtrade bananas are grown areas which currently have unstable rainfall during drier periods will become increasingly marginal for sustainable production. Increased attention will need to be given to water use efficiency, especially through the wider use of drip irrigation systems. In the Caribbean, the major threat will be from the greater prevalence of storm damage from increased hurricane activity.

Sugar cane

The available evidence on the potential impacts of climate change on sugar cane production suggests that, whilst enhanced levels of CO_2 may enhance plant growth the apparent benefits will not be seen when temperature is limiting. Thus in countries such as Brazil there may be yield gains, but these are unlikely to occur in countries such as Malawi and South Africa where temperatures exceed the mid-thirties degrees centigrade.

Section 4 sets out country-level projections, derived from the UNDP Climate Change Country Profiles, for 22 countries where Fairtrade commodities are produced. However, country-level climate projections, even before recognizing divergence between models and emissions scenarios, cannot be used in any straightforward manner to project impacts on particular crops. For more information will be needed on current climates and microclimates in areas where crops are grown, many of which are altitude-related and thus change significantly over small distances (particularly for tea and coffee).

Projected impacts on three countries are considered at slightly greater length: Kenya, where the major concern will be the effect of rising temperatures on the viability of tea and coffee; Mali where high temperature rises may be of concern for cotton, (although there is uncertainty in the literature) rice and fruit and vegetables; and the Dominican Republic, where impacts on coffee require further study, but impacts of rising temperature on cocoa and bananas may be less severe than the possibility of increased hurricane intensity.

Summary Table 1 Fairtrade crops and some examples of possible technological adaptations

Fairtrade crop	Possible technological adaptations
Rice	• Improving water storage and irrigation facilities • Development of drought tolerant varieties and diversification into suitable non-rice crops • Plant breeders to develop tolerance to salinity.
Cotton	• Changes to crop management practices to conserve water and reduce soil degradation. • Moving from surface furrow irrigation to sprinkler or drop irrigation greatly improves the efficiency of water use. • Greater use of minimum and zero tillage practices.
Vegetables	Impossible to generalise given the wide variety of crops and production systems.
Coffee	• More use of shade trees • Mulching coffee plants with the prunings from shade trees • Use of drought-resistant varieties • Supplementary irrigation.
Cocoa	• More use of shade trees
Tea	• Drip irrigation • More use of shade trees
Bananas	• Improving water use efficiency (e.g. by using drip irrigation systems) • Improving drainage and soil conservation on slopes • Black Sigatoka control strategies as key components of banana crop management systems.
Sugar cane	• Sprinkler irrigation

Section 5 looks at some of the literature on climate change impacts on agricultural trade, including projected higher food prices. This literature at present tells us little about prospects for Fairtrade, with uncertainties about the future of demand for non-necessities like coffee and chocolate, and for Fairtrade options with them, the impact of the growing debates about 'food miles', and the balance of rising prices and increased costs of production in many areas under climate change.

Section 6 reviews possible adaptations. Agronomic adaptation strategies are related to the particular climate trends they can respond to, and to the commodities on which they can be used.

Policy and institutional adaptations could include:

- Building up farmers' climate knowledge
- Integrating climate considerations into planning and impact assessment
- Supporting participatory adaptation processes at community level
- Providing financial support for transition to new varieties or crops
- Improving access to weather forecasts, including seasonal forecasts and early warning systems
- Promoting contingency planning and developing viable crop insurance models
- Supporting extension services that take climate change into account and build famers' own adaptive capacity
- Promoting environmentally farming, including linkages with conservation agencies, and with agroforestry initiatives
- Accessing climate change finance schemes
- Changing the content of producer standards, especially environmental standards, with accompanying capacity-building
- Promoting livelihood diversification and facilitating migration patterns that assist smallholders.
- Encouraging estates and other actors in value chains to fund and implement adaptations. Value chain partnerships should be sought with different actors in the value chain brought together to raise awareness of climate changes issues and responsibilities. It is important the burden of responding to climate change is not placed on the shoulders of already disadvantaged communities but that traders play their part as well, supporting learning, changing their practices and providing investment in local processes of adaptation.

Section 7 presents our conclusions. Desirable roles for Fairtrade are considered in the framework of building adaptive capacity and resilience, under six aspects: human, ecological, economic, social, physical and political. Alternatively, desirable changes are set out under the 'avenues of impact' of Fairtrade.

Summary Table 2 Fairtrade 'avenues of impact' for promoting climate change adaptation

Possible changes
Producer standards • Producer group and estate management/joint bodies could consider climate change in development plans • Strengthening of requirements for environmentally friendly and climate resilient farming • Encourage groups to consider use of Fairtrade returns and climate finance investment for contingencies and LH diversification where appropriate.
Trader standards • Grow markets to increase sales on Fairtrade terms and producer incomes/assets • Request traders to demonstrate the steps they are taking to reduce their emissions • Seek mitigation and adaptation partnerships with value chain buyers and actors to lever investment for smallholders and workers to measure their emissions and to invest in adaptations by farmers. • Increase requirements for longer-term trading relationships which enable producers to respond to longer-term adaptation needs as well as short-term priorities • Explore the potential for linking up to climate based index insurance • Consider how Fairtrade pricing should change if climate change affects the costs of production • Develop partnerships with value chain and innovation system actors to access investment, changes in relationships and learning processes to enable adaptation. Create 'ADAPTATION PARTNERSHIPS' with climate change thought leaders (e.g. the big retailers) to support adaptation amongst farmers and workers • Explore potential synergies with other environmental standards.
Capacity building • Raise awareness on climate change amongst farmer organisations, estates and worker groups • Support the sharing of accessible and clear climate information and improve access of farmers to climate information • Capacity building support for participatory adaptation planning and action • Technical support for agronomic adaptation and for social and financial innovations • Provide support for producer organisations and estates to tap into climate finance • Create new partnerships (e.g. with the meteorological services, with local government, with input suppliers, with other agricultural adaptation projects and programmes).
Networking, policy, advocacy, governance, research • Increase the voice of Fairtrade producers and workers in local and national adaptation and other relevant policy making (e.g. land reform, participation in adaptation planning processes). • Support representation from Fairtrade producers and workers in international climate policy arenas (e.g. the COP) • Integrate analysis of relative vulnerability/resilience into impact assessment • Educate Fairtrade consumers about the damage caused by their emissions and the importance of funding adaptation. • Assess the feasibility of creating direct linkages between consumers wishing to fund adaptation because of their unavoidable emissions and specific Fairtrade groups adapting to climate change.

Acknowledgments

Thanks are extended to Tanya Stathers and Richard Lamboll at NRI for their extensive comments.

List of tables

List of boxes

List of figures

List of diagrams

1. Introduction

Climate change poses significant challenges for the Fairtrade movement. There is mounting evidence that smallholder farmers in developing countries are experiencing increased climate variability and climatic change. It is expected that climate change will include more extreme events and slow onset impacts, such as changes in precipitation and temperature. Climate change is thought likely to have mainly negative impacts upon agricultural production, food security and economic development, especially in developing countries (see, for example, Hannah et al., 2005). It is now well rehearsed in the literature that the impacts of climate change will be felt most by the poorest who have least resources with which to cope and whose livelihoods are disproportionately reliant on climate-sensitive natural resources. Significant investment will therefore be required to reduce the adverse impacts of climate change on the very poorest and the rural poor more generally. Strengthening the adaptive capacity of, and promoting specific agricultural adaptations among, Fairtrade farmers and organisations will enhance their ability to respond to climate change impacts. New opportunities are arising, including tapping into climate finance mechanisms, which Fairtrade organisations may be able to access to both mitigate and adapt to climate change.

Many of the Fairtrade export crops, such as cotton, cocoa, coffee, tea, sugar, bananas, flowers, and citrus fruit, will be affected by climate change. Crops will respond in different ways to climate change: yields may increase or decrease and the places where crops can be cultivated may change. Assessing or predicting these changes, however, is difficult. Yields may be affected (possibly positively and negatively over different time frames and in different locations). The areas and the thresholds within which cultivation is feasible will also change as climate averages (temperature and precipitation) change. Whilst there is increasing analysis of potential climate change impacts upon agriculture and upon agricultural trade, this is still mainly restricted to the major cereal commodities wheat, rice and maize, and the implications for Fairtrade have not been adequately distilled.

The Fairtrade Foundation has commissioned this study to provide guidance to the Fairtrade movement as to how to respond to the challenges posed by climate change for Fairtrade producers. This paper provides a conceptual framework for understanding how climate change, agriculture and Fairtrade are interlinked. It is very important to note that many studies conflate climate variability with climate change. Farmers are widely reported to be experiencing increasing variability and increased frequency of extreme events now. We do not deny the reality or seriousness of these experiences of variability, but their relationship to global processes of climate change remains problematic. Climate changes more clearly linked to increased greenhouse gas (GHG) emissions, and in particular changes in average means (of temperature and precipitation), are only beginning to be apparent, and most projections of them look two or more decades into the future. This paper also presents an in-depth review of the scientific literature on the modelling of climate change impacts on crop production, with a specific emphasis on key Fairtrade countries and commodities. We also explore the evidence base on the potential trade impacts of climate change in key Fairtrade commodities, although it is important to recognise that Fairtrade growers will not only be affected by changes in crop yields, but by many other direct and indirect impacts of climate change. Finally, we analyse some of the adaptation strategies and approaches which could be supported by and through Fairtrade.

2. Conceptualising Fairtrade in agricultural commodities and climate change

This section explains the key concepts underpinning Fairtrade and agricultural adaptation in the light of climate change. We begin with an introduction to Fairtrade, to some of the key concepts relevant to climate change adaptation and to the types of climate change trends that may affect Fairtrade producers. A conceptual framework is then presented for understanding how climate change may affect smallholder agriculture.

2.1 Introducing Fairtrade

Fairtrade Labelling Organization International (FLO) certified Fairtrade has a number of mechanisms or 'avenues of impact' by which it seeks to achieve a positive impact for disadvantaged workers and producers (Eberhart and Smith, 2008)[1]. They comprise the producer and trader standards, against which producer organisations and estates are audited and certified, as well as capacity-building networking and advocacy activities by Fairtrade organisations (see Box 1). Capacity building can include technical support, assistance in organisational development, skills training and more empowering approaches which build confidence and assist less powerful groups to articulate their own narratives and priorities.

Fairtrade sales have increased dramatically over the last ten years reaching £2.89 billion globally by the end of 2008 (Nelson and Pound, 2009). Figure 1 demonstrates this rapid growth in the UK market.

2.2 Climate science, impact models and trends

Whilst climate predictions clearly project an unprecedented scale of change and local observations by farmers and others also indicate on-going climatic changes, moving from climate model outputs to a prediction of the likely impacts of climate change in specific places requires a further layer of modelling and therefore uncertainty (Ensor and Berger, 2009). There is a lack of downscaled data below national level. Models can be contradictory and smallholder livelihood systems are by their nature complex, diverse, locally specific, risky, exposed to a range of stressors, and dependent on on-going adaptive strategies making site specific predictions very difficult (Morton, 2010). Projecting agricultural impacts requires use of crop models based on known responses of specific crops to temperature, CO_2 and moisture and may also require models of land-use changes.

[1] Similar concepts are being applied to trade standards and impact: 'impact chains' (Nelson and Pound, 2009) and 'theories of change' in the ISEAL code of practice for impact assessment.

Box 1 FLO Fairtrade avenues of impact

Social development standards

For *small farmers*, FLO standards require:

- A non-discriminatory, democratic organisational structure that enables farmers to bring a product to the market
- The organisation must be set up in a transparent way
- It must not discriminate against any particular member or social group.

For *hired labour*, FLO standards require:

- The company involved to bring social rights and security to its workers
- Training opportunities
- Non-discriminatory employment practices
- No child or forced labour
- Access to collective bargaining processes
- Freedom of association
- Conditions of employment exceeding legal minimum requirements
- Adequate occupational safety and health conditions
- Sufficient facilities for the workforce to manage the Fairtrade premium.

Environmental standards

Fairtrade requires

- Minimised and safe use of agrochemicals
- Proper and safe management of waste
- Maintenance of soil fertility and water resources
- Organisations to assess their environmental impact and develop plans to mitigate it.

Fairtrade prohibits

- Use of genetically modified organisms

Trader standards

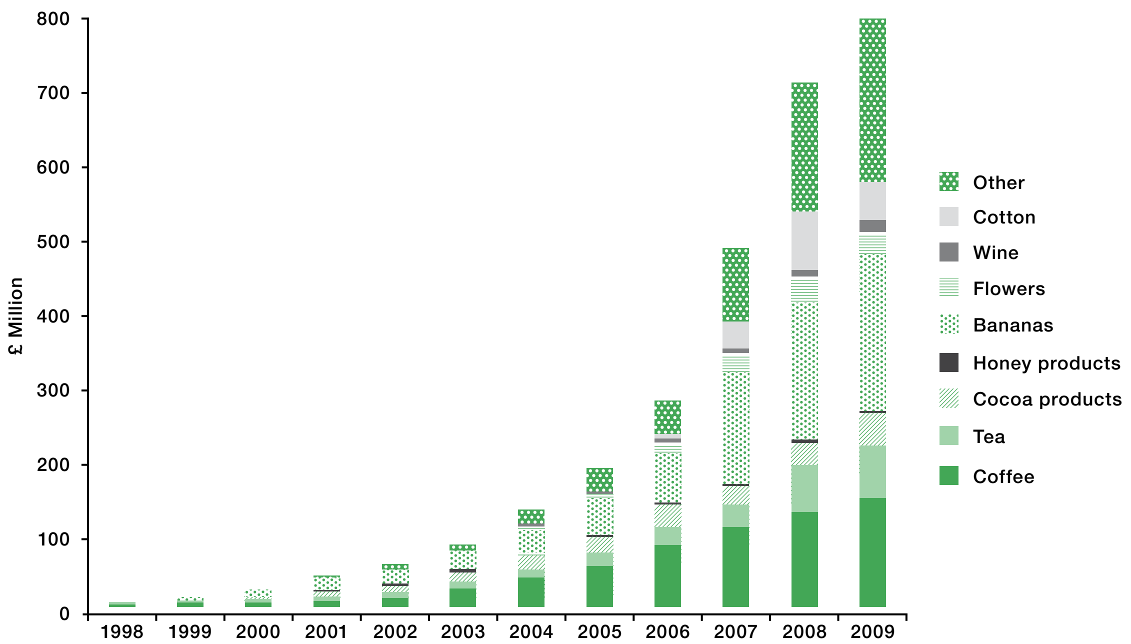
Fairtrade buyers are required to:

- Pay a stable Fairtrade minimum price calculated to cover the costs of sustainable production
- Pay a Fairtrade premium to producer organisations so that they can make livelihood investments and improve the situation of local communities
- Provide an opportunity for pre-financing
- Agree contracts that allow long-term planning.

Capacity building, networking, governance and advocacy

- Capacity building support is provided to small producer organisations by the Producer Support Unit of FLO, as well as by Alternative Trade Organisations (ATOs) in some value chains.
- Networking support is provided by FLO to existing and newly formed networks of Fairtrade producers (e.g. in West Africa, Central America etc) to help raise awareness of Fairtrade and to link up producers to new market opportunities.
- Governance – in recent years Fairtrade producer representatives have been elected to the board of FLO. This provides a mechanism for advocacy by producer representatives at FLO board level. Individual producer organisations may undertake advocacy activities particularly at the national level, although empirical evidence is lacking.

Figure 1 Sales of Fairtrade certified products in the UK



Source: Data from Facts and figures on Fairtrade from the Fairtrade Foundation website (note: these are estimated UK retail sales). ***www.Fairtrade.org.uk/what_is_Fairtrade/facts_and_figures.aspx?printversion=true***

Impact models employ 'physical and socio-economic models' to translate a 'climate future' (e.g. changes in temperature, rainfall and length of growing season) into human impacts (e.g. health implications, flooding, and food supply) (Ensor and Berger, 2009, p11). Many current studies conflate climate variability with climate change. To deal with current patterns of climate variability and increased extreme events, of which there are many reports, and to prepare for climate change many projects and programmes are exploring how to build resilience (the ability to cope with shocks and stresses) and improving community access to climate-related information (e.g. weather forecasts, seasonal forecasts and climate change models).

2.3 Vulnerability, Adaptive Capacity and Resilience

The term vulnerability in early work on risks/hazards focused on the biophysical threat (e.g. floods, hurricanes) as the point of departure and a particular exposure unit (e.g. place or sector) is assessed for vulnerability to a specific hazard. However, this understanding has evolved with later work on political economy, which critiqued this approach and made explicit the issues of resource allocation, social privilege and political disempowerment in shaping vulnerability. Finally, resilience thinking, has emerged in the 1980s and seeks understanding vulnerability and resilience (the ability to resist, cope with or recover from shocks and stresses) at a system level in a more dynamic sense, 'Why and how do systems change?', 'What is the capacity to respond to change?' And 'What are the underlying processes that control the ability to adapt?' (Eakins and Luers, 2006). So whilst the concept of vulnerability has long been used in disaster risk reduction and international development, in reference to social groups, communities and even nations that are considered particularly at risk from environmental or other phenomenon and may be in need of external support, in the context of climate change, the term 'vulnerability' has gained even greater currency. However, definitions tend to be loose and analysis of the *causes* of vulnerability should be emphasized to give greater precision (Cannon, 2008, after Blaikie, 1994).

The impacts of climate change will not be felt evenly, but will be overlaid upon existing patterns of inequality and are likely to exacerbate these (Nelson et al., 2002; Nelson and Stathers, 2009). Vulnerability is socially determined, with dimensions of gender, age, ethnicity, caste and class playing a key role in social differentiation – disasters can affect whole populations, but are most lethal when they hit an already poor and vulnerable population – i.e. groups of people without adequate livelihood resources to prepare, cope and recover. Reducing vulnerability to a particular hazard may thus need to involve 'no-regrets' actions which meet short-term needs whilst addressing potential longer-term climate change adaptation needs (Ensor and Berger, 2009).

Vulnerability is commonly broken down into three key elements: exposure, sensitivity and adaptive capacity (see table 1).

Agricultural adaptation efforts should thus aim to build the adaptive capacity of farmers and other stakeholders by helping them to actively create or respond to change. Resource entitlements (i.e. bundles of rights to resources which are claimed by a social group) are shaped by social identity, cultural norms, wealth and hierarchies. The poorest groups often have weak, ill-defined property rights. Inequality and poverty thus undermines adaptive capacity and should be challenged.

It is also worth nothing that the concept of vulnerability is often critiqued because of its associated connotations of powerlessness – a discourse which can become a self-fulfilling prophecy. A focus on capabilities and the resilience of individuals, households, and wider ecosystems and societies has gained attention in recent years partly to avoid this.

Resilience is the ability to cope with and recover from shocks and stresses and can apply to individuals, communities, ecosystems, organisations etc. Building up the resilience of individual farmers and communities has to be a critical objective of climate change adaptation and a characteristic of efforts made. Otherwise there is a risk that new adaptation options could leave farmers and communities more vulnerable to climate and other shocks and stresses. Some policies and development interventions could undermine resilience (e.g. solely focusing on cash cropping at the expense of food crops or on using expensive pesticides etc). Climate change imperatives are forcing greater consideration in development thinking of longer-timescales, but also

Table 1 Unpacking vulnerability

Exposure to specific climate risks: This refers to the geographical nature of climate risks, but social exclusion also operates on spatial terms with the poorest of the poor often forced to live on the steepest, fragile slopes and to cultivate in areas with poor quality soils etc.
Climate-sensitivity: Poor people's livelihoods and poorer countries are disproportionately reliant on climate-sensitive activities, including farming, fishing and collecting wild produce and woodfuel. Women are disproportionately affected because of their traditional gender roles (e.g. responsibility for the collection of water, edible wild plant and medicinal plant collection, crop cultivation etc) all of which may be negatively affected by climate change. In hard times in many areas of Sub-Saharan Africa labour migration intensifies, conducted mainly by men and leaving women and children to cultivate the fields and wait for remittances.
Adaptive capacity: The ability of individuals and communities to actively engage in processes of adaptation to climate change (by shaping, creating or responding to change) is contingent on livelihood resource entitlements (e.g. access to and control over credit, savings, land, water, information, social networks, political influence etc).

encouraging renewed emphasis on how change occurs in complex socio-ecological *systems* across scales. Shocks and stresses (disturbances) can be ecological, social or economic and unsustainable socio-ecological systems can be changed fundamentally and irreversibly by such disturbances[2].

Building up resilience reduces vulnerability to a wide range of hazards and in this way helps farmers and communities prepare for the uncertainties ahead. A number of indicators[3] of resilience are emerging which can be used to guide analysis of socio-ecological systems (e.g. Fairtrade farming in a particular location, or a watershed, city or particular wetland area) and to check that new adaptations to climate change will not leave farmers and others more exposed to shocks and stresses. At a community level resilience in disaster contexts has been defined as being the 'existence, development and engagement of community resources to thrive in a dynamic environment characterized by change, uncertainty, unpredictability and surprise. Resilient communities intentionally develop personal and collective capacity to respond to and influence change, to sustain and renew the community and to develop new trajectories for the communities' future' (Magis, 2007, p1). Key components of resilience to natural hazards (and longer-term climate trends) could include: baseline well-being, self-protection measures, livelihood strength, social protection and governance (Cannon, 2008)[4].

All forms of resilience are important: Tackling inequality is a key part of building *social resilience*, including supporting participation of disadvantaged groups in decision-making. Building *ecological resilience* is also important as ecosystems provide key services for rural livelihoods and a healthy environment acts as a buffer to shocks and stresses, whereas localised processes of environmental degradation increase local people's vulnerability to climate related hazards. Environmentally-friendly farming and promoting agrobiodiversity will increase resilience to climate shocks and stresses[5]. Economic resilience means diversifying the income sources and livelihood activities and access to assets. This could mean diversifying the crops grown, but could also involve more non-farm activities which are playing an increasingly important role in rural

Box 2 Resilience and diversity

One of the key indicators of resilience is diversity. Ecologists recognise both effect and response diversity (species have traits which shape their effects on ecosystem processes and traits that govern the response of species to environmental variation) (Chapin et al., 2009). The biodiversity effects on ecosystem services can be divided into: functional composition, numbers of species, genetic diversity within species, and landscape structure and diversity (Chapin et al., 2009). Increasing diversity can generally speaking increase resilience:

- Agro-biodiversity and planting on different terrains has long been recognised in agro-ecology as a critical strategy employed by small-scale farmers, drawing upon their local and indigenous knowledge, to spread risk. Mono-crop farm systems are more susceptible to plant diseases which will increase with climate change.
- Diversity of assets and livelihood strategies helps farmers and urban dwellers to spread risk. However, at some point spreading of assets may reach a limit and accumulation of assets, such as savings, may be more important to help a household cope (Ensor and Berger, 2009).
- Involvement of multiple stakeholders in decision-making may help to reduce potentially damaging policy developments (Ensor and Berger, 2009).
- Social protection by governments and international organisations is also important to compensate for a lack of diversity and to back-stop specialization (Ensor and Berger, 2009). A whole range of interventions exist, many of which have already proved effective and which could become increasingly relevant as climate change occurs, including cash and asset transfers, seed fairs etc, although these also need to be adaptive (Nelson, forthcoming).

---

[2] Types of actual or potential disturbances may be ecological (e.g. drought, fire, disease, hurricanes and floods); economic disturbances (e.g. recessions, market volatility); or social (e.g. revolutions, new connections, new values, technological developments). Key questions also include: How frequent are these disturbances (frequency, duration, severity, predictability)? Pulse disturbances occur and then cease before recurring, (e.g. application of new fertilizer, hurricanes, disease outbreaks) and press disturbances are unremitting (e.g. grazing land that is stocked year round). Do the disturbances compound eachothers' effects or *vice versa*? It is worth noting that management strategies which attempt to control disturbances (e.g. by reducing vulnerability) can erode the resilience of a managed system, making it susceptible even to small disturbances (Resilience Alliance, 2007)

[3] Such indicators include diversity, social networks, innovation, redundancy, ecosystem services, tight feedbacks, modularity, overlapping governance, acknowledging slow variables (Walker and Salt, 2006).

[4] Baseline well-being of household members (nutritional status, physical and mental health, morale); self-protection (the degree of protection afforded by capability and willingness to build safe home, use of safe site); livelihood resilience (e.g. access to and control over assets); social protection (forms of hazard preparedness provided by society more generally, e.g. building codes, GHG mitigation measures, shelters, preparedness); governance (i.e. power relations, social networks, institutional environment).

[5] An Indian company which is acting as a promoting body in cotton under the contract production standard (CPS) is promoting a particular high yielding cotton variety amongst the smallholder farmers it is providing services to and buying from. However, this variety is also more drought prone leaving farmers more vulnerable to drought. Farmers in the association who were recently interviewed said that they were continuing to grow traditional, more drought tolerant varieties alongside the more drought prone one to continue to spread risk. This raises questions for Fairtrade organisations and promoting bodies about balancing the need to support farmers to increase their incomes whilst also avoiding increased risk in the light of intensifying climate hazards, such as drought (Nelson and Smith, forthcoming).

household budgets (e.g. working locally or at a distance when less work is required on farm). It is necessary to strike a balance between diversifying and building up assets (e.g. stocks and savings) as the latter also increases a household's ability to cope with shocks and stresses.

2.4 Stakeholder climate knowledge

The uncertainties in climate science and modelling have been outlined above. Beyond this uncertainty there are also variables levels of access to and interpretations of this climate information by different stakeholders. Moreover, at the local level different individuals and communities will have diverse experiences of climate, different worldviews that shape their ideas of what the climate is and what might drive changes in it (including religious and spiritual beliefs) and different sets of resources to respond to climate information and to take action.

Analysis of the levels of clarity about climate knowledge and vulnerability of social groups or communities to a particular hazard or set of climate change trends is therefore a good starting point for a situation analysis and for identifying entry points for action in the 'adaptation space'[6] (Ensor and Berger, 2009).

- An assessment revealing *low clarity* of climate knowledge might focus efforts on improving understanding and increasing investment in climate modelling, or on building the capacity of networks to demand access to more relevant climate knowledge from existing knowledge holders. Generally speaking building adaptive capacity and resilience can help provide a buffer to a lack of knowledge.
- *High levels of clarity* of climate knowledge and high vulnerability to a particular hazard can inform adaptation responses, and implementation on the ground or scaling-up may be the priority. Low vulnerability demands little action to respond to a hazard, but high vulnerability requires urgent action. High vulnerability requires action shaped by the key issues identified in the starting-point vulnerability analysis.

2.5 Climate change impacts on smallholder agriculture

The scientific projections for climate change indicate:

a) Increased extreme events

b) Greater climate variability

c) Changing means (e.g. in average temperatures and precipitation).

The *impacts* can be divided into direct and secondary impacts (Anderson et al., 2009):

- The *direct impacts* of climate change will operate at three different levels: i) on biological processes at organism or farm level; ii) on environmental and physical processes at production and landscape level; iii) on human health and non-agricultural livelihoods.
- The *secondary impacts* of climate change comprise:
  - distant, off-site impacts of climate change on a particular smallholder system;
  - impacts of climate change adaptation and mitigation policies, programmes and funds.

This typology is summarised in table 2.

The secondary or indirect impacts of climate change include the distant, off-site impacts that may occur as climate change impacts affect one population leading them to undertake adaptations (modifications and more radical changes) creating impacts on another location. This could occur through market mechanisms or population movements for example. Secondary impacts will also occur, because of the responses initiated by governments, development agencies, NGOs and the private sector.

New policy frontiers have emerged in climate mitigation, adaptation and development futures (Boyd et al., 2009), but whether climate policies and programmes lead to new opportunities for low carbon development and improved wellbeing or exacerbation of existing social inequality and environmental degradation remains to be seen. If adaptation and mitigation responses are not implemented in a gender-sensitive manner, and if appropriate participation of women and socially excluded groups in relevant policy and decision-making is not improved then social inequalities could be exacerbated and their priorities ignored (Nelson et al., 2002; FAO, 2007; Dankelman, 2008). Debate about the trade-offs required in adaptation decision-making[7] is needed as decisions become more complex given the uncertainties, but also seriousness of climate change projections. The question of whose voice is heard in this decision-making will be more important than ever, and increased support is needed for participation of marginalised groups in adaptation policy processes[8].

Climate change risks are not the only challenges faced by smallholders. The impacts of climate change will interact with multiple other non-climate rural and urban stressors. The stressors which specifically prevent *agricultural* development in developing countries include weak governance, land fragmentation, regionalizing and globalising markets, the spread of HIV/AIDs etc (see annex 1), especially in Sub-Saharan Africa. More mapping of the *combined* vulnerability of rural populations to climate change and non-climate stressors, such as that carried out on climate change and market vulnerability by O'Brien, Leichenko et al.. (2004), is also urgently needed. The management of non-climate stressors (e.g. tackling population trends, social inequality etc) can be considered an adaptation response in themselves. For

[6] 'Adaptation space' being an arena for action on adaptation.

[7] Decisions leading to high adaptedness now (e.g. building sea dykes) may protect vulnerable groups but may foreclose on different future pathways. Conversely, retaining flexibility given the uncertainties of climate change may have implications for currently vulnerable groups, but may keep open a broader array of future pathways which benefits future populations (Nelson, Brown and Adger, 2007)

[8] A strong element of climate change adaptation involves back-casting (defined as 'Identifying societal goals and working backwards to explore how to arrive at them. Often used with simulation models and scenario analysis.' Chapin et al, 2009, 342). Back-casting usually involves participatory processes of multi-stakeholder engagement and learning alliances and are important for building awareness of climate change amongst key stakeholders, promoting social learning, potential actions/pathways as well as creating momentum for collective action.

example, improving policies relating to population trends (e.g. increasing educational opportunities for girls, greater economic opportunities for women and expanded access to reproductive health and family planning) may also build resilience to climate change. However, more specific actions to manage climate risks will also be needed and even (probably costly) measures to confront climate change where human-induced climate change is already clear (e.g. where sea level rise or salt water intrusion is occurring) (McGray et al., 2007).

2.6 Agricultural innovation systems

Interventions to bring about agricultural development have traditionally focused on technological innovation, such as varieties and breeds, types of equipment and methods used, to increase growth or cut costs, reduce risks, enhance quality etc. However, in recent years there has been increasing recognition that social and institutional innovations can be just as important, e.g. formal or informal group formation, such as the development of co-operatives, farmer groups and self-help groups or development of new linkages and networks between producers and service providers (Conroy in Snapp and Pound, 2008).

Innovation systems approaches are used both to analyse and to promote innovation. They look at larger networks of actors, link research and education systems, link formal research capacity to community research capacity, link the private and public sectors, strengthen organizational mechanisms at the local level, and seek to transform the attitudes and practices of key actors through collaboration, partnerships, and patterns of trust and cultures of innovation (World Bank, 2006).

The existing agricultural knowledge and capacities of smallholder farmers should be properly valued and should form the starting point for external adaptation processes. Poor farmers face many barriers limiting their opportunity to innovate and there are risks to food security and household income to changing long-held practices. However, some farmers do innovate and particularly with external support farmer groups (e.g. in farmer field schools, farmer-to-farmer extension) can learn together how to develop and share new technologies and practices. Farmers should thus be recognised as potential innovators and placed 'centre-stage' in agricultural adaptation, whilst recognising that to achieve a well functioning and responsive agricultural

Table 2 Typology of impacts of climate change on smallholder and subsistence agriculture

Direct climate change impacts upon smallholder livelihoods	
Biological processes affecting crops and animals at the levels of individual organisms or fields	Direct impacts of changes in temperature, carbon dioxide, and precipitation on yields of specific food and cash crops and productivity and health of livestock. Can include impacts of variability in temperature and precipitation e.g. hot or dry spells at key stages in crop development. Also includes changed patterns of pests and diseases.
Environmental and physical processes affecting production at a landscape, watershed or community level	Smallholder agriculture will be affected by direct impacts at the level of communities, landscapes, and watersheds (some overlaps with studies on extreme events). e.g. decreased availability of water in the irrigation systems of the Indo-Gangetic plain; impacts on soil processes from complex global warming impacts and associated hydrological changes (accelerated decomposition of organic matter, depression of nitrogen-fixing activity), soil fertility and water holding properties affected, and overall soil erosion exacerbated by increased erosivity of rainfall.
Impacts of climate change on human health	The above impacts on agriculture will be combined with impacts on human health and the ability to provide labour for agriculture, such as increased malaria risk.
Impacts of climate change on non-agricultural livelihoods	Impacts on important secondary non-farm livelihood strategies, e.g. tourism, for many rural people in developing countries.
Secondary or indirect impacts of climate change	
Distant, off-site impacts of climate change on a particular smallholder system	Impacts of climate change in other distant areas may create changes which affect a smallholder system. For example, decreased supply of grain in one location might affect specialist cash-crop producers in another area as the latter are net grain buyers.
Impacts of climate change adaptation and mitigation policies, programmes and funds	The secondary impacts of climate change occur as governments, civil society, the private sector etc gear up to respond to climate change and institute new policies, programmes, and funds – all of which may impact upon smallholders (positively or negatively). An example would be leasing of agricultural lands to agri-business for biofuel production

(Adapted from Morton, 2007; Morton, 2010, Anderson et al*, 2009)*

innovation system needs commitment and engagement by other stakeholders. 'Farmer first' (Chambers et al., 1989) approaches and participatory agricultural development have in recent decades shown that rural households have diverse livelihood strategies and that farmer experimentation is continuous (in relation to annual crops) in response to climate variability and other pressures and that the performance of agriculture is a learning process in which scientists should participate – not the other way around. Support to farmer innovators is also a key part of participatory technology generation and farmer-to-farmer extension. However, other actors in the innovation system are key to adaptation, such as other value chain actors (e.g. input suppliers, traders) and those that shape the regulatory and institutional environment (e.g. government departments, policy-makers etc).

Much of the literature on agricultural adaptation to climate change implies that adaptations are continuous because they are referring to annual crops, but some changes made where perennials are concerned are by nature abrupt rather than marginal (e.g. planting new varieties with long lead-time to an economic yield, or uprooting existing plants).

Generally speaking agricultural innovation processes in the light of climate change should be decentralized to cope with the diversity and local specificity of smallholders systems, participatory to build on farmer knowledge, and to cope with the complexity of farming systems, multi-stakeholder (for example involving government at various levels, and the private sector, alongside farmers and researchers), to incorporate wider perspectives and to feed upwards into policy and investment decisions, incorporating capacity building for stakeholders (Morton, 2010), gender sensitive, and should aim to build resilience.

2.7 Types of adaptation responses

Adaptation responses can include a variety of actions from those that are more vulnerability-oriented and generic to ones which are more impact-oriented and more specific to climate change. A continuum of adaptations from vulnerability to impact focused activities is set out below (after McGray et al., 2007):

i. actions to tackle the underlying drivers of vulnerability (e.g. literacy programmes, HIV/AIDs) which do not necessarily consider climate change)

ii. actions to build response systems for problem solving and capacity for targeted responses (e.g. developing robust communication and planning processes, improving mapping and also weather monitoring and natural resources management practices (e.g. participatory reforestation on flood prone slopes).

iii. actions to manage climate risk (hazard effects which are not easily distinguishable from hazard effects in the historic range of climate variability). Managing these risks requires climate information to be integrated into decision-making to help reduce the negative impacts of climate change on livelihoods and resources, e.g. developing drought resistant crops, disaster risk management activities, and efforts to climate proof infrastructure.

iv. actions which clearly address climate changes which are human-induced (e.g. measures in response to increasing glacial lake outburst risks, or managing coral reefs where bleaching is widespread, or building sea dykes to cope with sea level rise. These are highly specialized activities, which can be costly and require political will, and may foreclose on alternative, future development pathways.

Many of the actions which will be needed are already in the 'development toolbox' (McGray et al., 2007) or perhaps in the agro-ecological toolbox, but innovations will also be needed (e.g. adapted varieties, better access to forecast information, changes to building specifications) and farmers are likely to require external support because climate change may outstrip their existing knowledge and practices and they and policy-makers/planners need assistance to look beyond two to three years to the longer-term.

In agricultural adaptation in Fairtrade there are some actions farmers that may already be doing. We suggest that most adaptations will require some level of new learning and external support, (training and capacity building), and/or external financing, and finally other actions will require facilitation of multi-stakeholder collaboration and learning, and institutional or broader systemic changes.

2.8 Conceptualising agricultural adaptation

Work on adaptation to climate change is burgeoning, but literature and guidance on agricultural adaptation *specifically* is more limited, although more work is beginning to emerge. Howden et al. (2007), for example, divide adaptation into two: farm level changes in farming practices to *maintain* existing system and wider institutional and policy changes which may be more significant and *systemic* in nature. Agricultural adaptation can thus be thought of as modifications to an existing system or a wider set of changes, but in fact both will be required, alongside new approaches and social learning to respond to climate change (Howden et al. 2007). Farm level changes could include changes in varieties, planting times and use of conservation tillage. These changes are made at the management unit decision level in cropping, livestock, forestry and marine systems. Broader scale changes might involve redistribution of resources, changes in land use, support for new livelihood options etc. These broader changes involve changes in the decision environment (e.g. policy changes to encourage behavioural and institutional change amongst enterprises and farmers (Howden et al., *ibid*) – see Table 3.

Finally, in thinking about and trying to understand agricultural adaptation processes it is necessary to look across scales, time and types of decision. Risbey et al. (1999) suggest that adaptations oriented towards short-term modifications in the farming environment (e.g. droughts, market fluctuations) may be limited in their efficacy by constraints imposed by broad changes in the soil, water and economic environment occurring over longer-time scales – and that different actors will be involved depending upon whether decisions are tactical, strategic or structural. Thus tactical decisions about practices in the next season or year may involve farmers, insurance agencies, markets, and regional agricultural agencies. Strategic decisions, which cover multiple years (1-5 years) may involve farmers and regional agricultural agencies. Finally, structural decisions (concerning multiple decades) are more likely to be in the domain of national governments and regional agricultural agencies (Risbey, et al., 1999).

Table 3 Avenues for changing management behaviour in the light of climate change

Convince managers of the reality of climate change	Policies which maintain climate monitoring and effective communication of this information (incl. targeted support of surveillance of pests, diseases etc)
Convince managers that projected changes will impact upon their enterprise	Policies that support the research, systems analysis, extension capacity, industry, and regional networks that provide this information could thus be strengthened. This includes modelling techniques that allow scaling up knowledge from gene to cell to organisms and eventually to the management systems and national policy scales.
Support increased access to technical and other innovations	Where existing technical options are inadequate, investment in new technical or management strategies may be required (e.g., improved crop, forage, livestock, forest, and fisheries germplasm), including biotechnology. In some cases, old approaches can be revived that may be suited to new climate challenges
Effectively plan for and manage climate-induced transitions in land use	Transitions of land use may include migration, resettlement and industry re-location. Provide direct financial and material support, creating alternative livelihood options with reduced dependence on agriculture, supporting community partnerships in developing food and forage banks, enhancing capacity to develop social capital and share information, retraining, providing food aid and employment to the more vulnerable, and developing contingency plans. Effective planning and management may result in less habitat loss, less risk of carbon loss and also lower environmental costs compared with unmanaged reactive transitions
Support new management and land use arrangements	Enable new management and land use arrangements via investment in new infrastructure, policies, and institutions. Addressing climate change in development programs; Enhancing investment in irrigation infrastructure and efficient water use technologies; Ensuring appropriate transport and storage infrastructure; Revising land tenure arrangements, including attention to property rights; Establishing accessible, efficient markets for products and inputs (seed, fertilizer, labour, etc.) and for financial services, including insurance.

Source: Adapted from Howden et al*, (2007)*

Moreover, adaptations are undertaken in the light of specific normative goals, raising the question of 'adaptation and resilience for whom?'.

Studies show that agricultural or agronomic adaptations (including many based on existing practices by which farmers adapt to/cope with climate variability) will have some efficacy in the face of climate change. Howden et al. (2007), work with a large sample of simulation studies for wheat yields under climate change (for details see Easterling et al. 2007) to summarise the benefits of adaptation in terms of the difference between percentage yield decreases with or without agronomic adaptation. Wheat is of course not a Fairtrade commodity or closely related to any Fairtrade commodity, and the table aggregates simulations of temperate and tropical production, but the technical possibilities of adaptation, particularly for smaller temperature increases accompanied by rainfall increase, are clear and demonstrate the importance of adaptation.

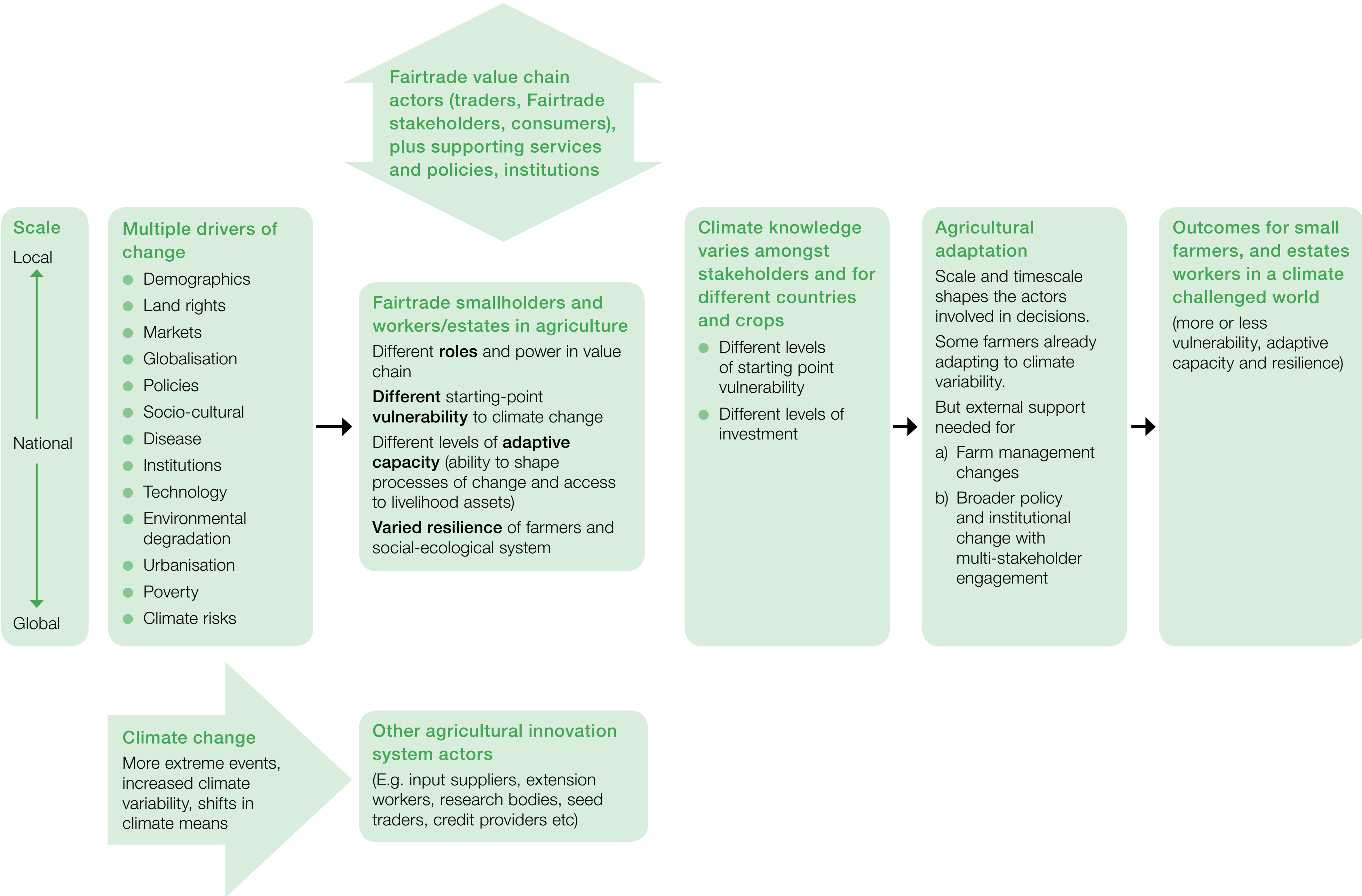
Diagram 1 visualizes the key elements of the Fairtrade-climate change-agriculture nexus. It shows how multiple stresses including climate change affect Fairtrade farmer and workers. Fairtrade farmers and workers (that are part of both the Fairtrade value chain but also wider agricultural innovation systems) have different levels of vulnerability, adaptive capacity and resilience to these pressures and shocks. All the actors adapting to climate change face uncertainties in the climate change science and impact modeling (although some locations and crops more than others) but there are also differences in access to information and interpretations of climate. Adaptations are already being undertaken by farmers at the farm level but more external support may be required to support these and to achieve broader changes in the decision environment (e.g. in policies).

Table 4 Mean benefits of adapting wheat cropping systems to impact of temperature and rainfall changes, calculated as the difference between percent yield changes with and without adaptation

Temperature change	< 2°C	2-4°C	>4°C
With rainfall increase	27	19	17
With rainfall decrease	9	11	15

Source: Howden et al.*, (2007); original also includes standard errors*

Diagram 1 Climate Change and Adaptation in Fairtrade Agriculture



3. The effects of climate on selected Fairtrade crops

This section reviews the scientific literature on climate change and some of the most important crops traded under Fairtrade labelling schemes. Not surprisingly, we did not find literature that distinguished between Fairtrade commodities and the same crops conventionally traded. Additionally, much of the generic literature on agriculture and climate change focuses on the three major cereal crops of rice, wheat and maize of which only rice is Fairtrade commodity.

It is well known that the trapping of long wave radiation by atmospheric greenhouse gases (primarily carbon dioxide, CO_2, and water vapour, H_2O) keeps the atmosphere, and hence the planet, approximately 30 °C warmer than it would otherwise be (see, for example, Jain, 2009). Since the 1980s, however, it has been recognised that an increase in the amount of atmospheric CO_2, as a direct consequence of human activities, has been taking place, with an increase from pre-Industrial levels (1750) of *c*. 280 ppm to, currently, *c*. 388 ppm (Houghton, 2009; NOAA, 2010). This has led to a mean temperature rise over the 20th century of 0.6 °C +/- 0.2 °C, specifically since the 1980s (IPCC, 2007).

Future projections of global warming are difficult, as there are different scenarios for the rate and nature of economic growth and thus the rise in GHG emissions and as different climate models give different results, but there is agreement that the world will get warmer as CO_2 levels continue to increase (IPCC, 2007). The magnitude of the global temperature rise is predicted to be at least 0.2 °C per decade for the next two decades. After this period, it is anticipated that temperatures will rise by at least 0.1 °C per decade, even if emissions of greenhouse gases and aerosols are held constant at year 2000 levels. However, one model is predicting a temperature increase of up to 6 °C by 2100 and this would have devastating ecological consequences (IPCC, 2007).

Model predictions indicate that there will be important variations in changes in temperature and rainfall so that some areas are likely to become warmer and others cooler. Similarly, some locations will be wetter and others drier. These changes will affect the length of the growing season, with potentially serious impacts for the production of crops such as maize in parts of Africa. Reduced snowcap in the Himalayas will affect water flows in some large river systems in Asia and therefore limit the availability of water for irrigation. Rises in sea level due to warming will affect the production of rice and other crops due to the incursion of saline water.

3.1 Plant responses to increases in CO_2

When the problems of increasing atmospheric CO_2 were first identified there was an assumption that increased vegetation, through planting additional crops and trees and/or through increased biomass from current levels of crops and trees, would result in CO_2 harvesting from the atmosphere: effectively, it was thought that global warming could be beneficial to agriculture. It is now recognised that the likely impacts are much more complex. Whilst there may be short-term gains in crop production through the so-called 'fertilisation effect', increases in CO_2 levels and temperature, and changes in precipitation patterns, will, singly and together, act to change crop ranges and productivities in more complex but generally negative ways. These are as a result of direct effects on crop physiology. There will also be associated changes in the movement of crop pests and disease, thereby changing the dynamics of these interactions (Harrington & Woiwod, 1995; Bale et al., 2002). There is debate within the scientific literature as to the relative order of importance of these effects.

Although they all operate in the same general way, using sunlight to convert CO_2 and H_2O to energy in the form of glucose, the three biochemical pathways of photosynthesis (C_3, C_4 and CAM) have evolved depending on the plant environment, and are defined by the nature of the first product of CO_2 assimilation (Cowie, 2007). Many tropical grass species are C_4 photosynthesisers, including maize, sorghum and sugar cane, whilst temperate environments suit C_3 plants; for example wheat and barley, although rice is also a C_3 plant (Drake et al., 2005; Cowie, 2007; Sadava et al., 2008). Crassulacean Acid Metabolism (CAM) evolved independently in plants such as the cacti and other succulents (including the pineapples), suited to semi-arid environments.

In evolutionary terms, C_3 is the oldest form, with C_4 plants evolving approximately 25 million years ago (Cowie, 2007). C_4 plants are more efficient at lower concentrations of atmospheric CO_2, so, broadly, any increase in CO_2 is likely to benefit these plants least (Drake et al., 2005; Cowie, 2007). However, assessing and predicting plant photosynthetic response to increases in CO_2 is difficult and the results are sometimes contradictory. In addition, confounding effects of increased temperature (as a consequence of increased atmospheric CO_2 concentration, see below) and changes to plant biochemistry are also likely to change the palatability of crops to human and other consumers, as well as the geographical regions of cultivation. It is also likely that changes in atmospheric CO_2 concentration will result in changes to the dynamics between crops and weeds.

C_3 plants respond with increased photosynthetic rates but with decreased leaf nitrogen levels when grown under enriched CO_2 levels (Rogers et al., 1983). Under controlled conditions, C_3 plants show increased growth under increasing CO_2 concentrations, compared to C_4 plants (Patterson et al., 1999), but this is less evident at higher temperatures. Some C_4 crops respond less vigorously to increased CO_2 than others do and these include maize and sorghum. Considering data from a range of crop species it appears that, on average, yields at 550 ppm CO_2 (compared to current levels of 380 ppm) increase by 10–20 percent for C_3 crops and up to 10% for C_4 crops (Tubiello et al., 2007). Similar levels of CO_2 in the atmosphere may increase production in different pastures and rangelands by up to 20 percent, depending on water, temperature and nutrient limitations (Nowak et al., 2003). In addition to reports of the short-term effects of increased CO_2 on temperate forests, the growth and productivity of lowland moist tropical forest under similar conditions is expected to increase, although this will vary with nutrient supply (Norby et al., 2003).

Most plants are expected to show a decrease in nutritional quality, especially if leaf nitrogen drops, and this might affect insect pests feeding on them. Increased levels of atmospheric carbon will result in greater carbon to nitrogen ratios in plant foliage, which may stimulate greater feeding activity in some herbivores. This, together with the fact that host plant quality is often increased by drought-induced plant stress, is likely to result in increased feeding by pests and lead to greater crop damage (Hill & Dymock, 1989; Porter et al., 1991). On the other hand, carbon-based defence mechanisms in plants may increase as atmospheric CO_2 concentrations increase so the effects on insect feeding are not clear and are likely to vary.

3.2 Changes in temperature

Aside from the direct response of photosynthetic pathways to increased concentrations of atmospheric CO_2, the associated increases in temperature will also affect plants. Unfortunately, whilst a global increase in temperature is an agreed outcome of climate change, the magnitudes of such increases, especially on regional and sub-regional scales are subject to great uncertainties, even when projections have been made for specific localities.

Because each plant has an upper and lower threshold temperature which controls its range, temperature is one of the main factors governing plant migration to new areas under the various climate change scenarios, as well as the survival of plants within their current ranges. Plants vary considerably in their tolerance to high temperatures. In general, agricultural plants are less well adapted to high temperatures than wild plants and they are less able to use avoidance or escape mechanisms (e.g. pore closure, orientation to shade). Moreover, tolerance to high temperatures in agricultural plants has been reduced through selection processes which are mainly guided by the search for higher yields.

Adverse effects of elevated temperature on crop plants may result from increases in average temperatures, high maximum temperatures or increases in the diurnal temperature range (Lobell, 2007). These effects may also be modified by other factors such as water availability. Temperature effects on crop plants may be manifested indirectly. For example, high temperatures may cause increased mortality of pollinators and affect populations of pests and diseases and natural enemies (Chancellor & Kubiriba, 2006; Chakraborty et al., 2008). These effects may be positive or negative depending on the cropping system. Increased temperatures may also favour the growth of weed species enabling them to compete more effectively with crop plants. The response of crop plants to temperature stress depends upon several factors. These include the crop growth stage (Porter and Semenov 2005), the type of plant tissue and the nature of temperature stress. For example, high soil temperatures may affect the seedling stage of certain crops such as cotton (Nabi & Mullins, 2008) and upland rice.

In one recent study, historical temperature data were compared with projected future temperatures in each of the countries in Africa and the implications for three cereal crops (maize, wheat and sorghum) were examined (Burke et al., 2009). The model projections revealed that, for each of the three cereal crops examined, temperatures within their current range are likely to increase significantly. On average, by 2050 temperatures in most years are predicted to be higher than those in any year that has been experienced to date. One of the consequences will be marked changes in the suitability of land for cultivation of particular crops (Devereux and Edwards, 2004).

3.3 Changes in precipitation

There is much less certainty attached to rainfall projections under different climate change scenarios. However, an increased frequency in drought events is likely to be one of the most serious consequences of projected global warming, globally, but particularly in sub-Saharan Africa and most of Asia and Australia (IPCC, 2007). A shortage of water affects plants by reducing the rate of photosynthesis, either through a direct effect of dehydration or through stomatal closure which reduces CO_2 intake (Seth & Amthor, 2004).

An increased frequency and severity of drought events will mean that some areas which are currently marginal for the production of some rainfed crops will no longer be suitable for production. For example, in some areas of maize production in southern Africa there is already a high risk of significant yield loss or crop failure. An increase in the number of dry days or in the frequency of the early cessation of rains would make maize production unsustainable (Tadross et al., 2005).

Where this is feasible, supplementary irrigation will be needed to counterbalance the higher soil moisture deficits. It has been estimated that globally, even taking into account greater water use efficiency resulting from higher levels of CO_2, there will be an increase of around 20% in net irrigation requirements by 2080 (Fischer et al., 2007). This increase will be larger in developing countries so the impacts will be greater for smallholder farmers.

3.4 Implications for crop production

Modest increases in temperature may lead to increased yields of cereal crops in temperate regions. By contrast, in tropical regions even a modest temperature increase of 1–2 ^{O}C is likely to result in yield losses in rice, maize and wheat, although the use of adaptation measures may modify this response (Tubiello et al., 2007). Overall impacts of climate change will vary between regions, with dry areas particularly affected. It has been estimated that, by 2080, there will be an increase of 5 to 8 percent in the area of arid and semi-arid land in Africa (Easterling et al., 2007). This will have implications for the range of crops that can be produced in these areas.

In the following sections, the available information is examined for several of the key Fairtrade Foundation crops.

3.4.1 Rice

The geographical range of rice (*Oryza sativa*) is 50 ^{O}N (Aihwei county, China) and 35^{0} S (New South Wales, Australia) (De Datta, 1981). The majority of rice is grown in the tropics and subtropics, but the highest yields are obtained in temperate regions where levels of solar radiation are relatively high during the growing season.

Rice is grown in a wide range of ecologies with varying rainfall patterns. The seasonal distribution of rainfall is a crucial determinant of the suitability of a region for rice production, particularly in upland rice cultivation. Significant moisture stress occurs where monthly rainfall is less than

200mm, particularly during extended periods of up to three weeks with no rainfall (De Datta, 1981). Where irrigation is available, planting dates can be timed to coincide with optimum temperature and solar radiation levels (temperate zones and dry seasons in the tropics). In practice, there are other factors which influence planting dates such as availability of labour and credit to purchase needed inputs.

Flowering in rice generally occurs over a five day period and is strongly influenced by temperature. The flowering times of *glaberrima* (African) sub-species are earlier in the day than for *indica* and *japonica* types, when temperatures are cooler, and this may be a useful trait to incorporate into rice breeding programmes. Elevated temperature at flowering, even over a short period, has a significant effect on rice yield as this causes spikelet sterility. However, the effects are not restricted to impacts on fertility *per se*. It has been shown in glasshouse experiments that temperature may influence the number of spikelets reaching anthesis (flowering). In these experiments, significantly fewer spikelets of a *japonica* variety reached anthesis with daytime temperatures of 36.2 ^{O}C compared to 29.6 ^{O}C (Jagadish et al., 2007). By contrast, a significantly larger number of spikelets reached anthesis in an *indica* variety that was tested. In both varieties, sterility resulted from exposure to a temperature of ≥ 33.7 ^{O}C for periods of an hour or less at anthesis.

These findings accord with field observations in China. An analysis of variations in temperature and yield at several locations revealed that there was a positive correlation between spikelet sterility in rice and maximum temperatures during the twenty days before and after flowering (Tao et al., 2006).

Elevated CO_2 may stimulate plant growth and increase grain yield, but this effect is reduced when there are high night temperatures (Cheng et al. 2009). Recent studies have been conducted on the impacts on rice yields of changes in diurnal temperatures. The diurnal temperature range (DTR) is defined as the difference between daily maximum and minimum temperature. An analysis of cereal yields across a range of countries showed that in several rice growing regions there was a significant decline in yields in response to increased DTR (Lobell, 2007). The rice growing regions studied included China and India, the two largest producers of rice. However, in research carried out on the experimental farm at the International Rice Research Institute in the Philippines, it was found that higher night temperatures (and therefore a reduced DTR) resulted in significant yield loss. For each 1 ^{O}C increase in minimum temperature in the dry season from 1992 to 2003, average yields declined by 10%. It is apparent that further studies are needed to clarify the effects of DTR on rice yields.

In parts of tropical Asia, rice production may be significantly affected by annual and inter-annual variations in rainfall resulting from the El Niño-Southern Oscillation (ENSO) cycle. During the warm phase of the ENSO cycle (El Niño) there are extended dry periods which reduce agricultural production and lower the incomes of smallholder farmers (Naylor et al., 2001). Recent projections of the future impacts of El Niño events suggest that by 2050 there will be a substantial increase in the probability of a 30-day delay in the onset of the monsoon (Naylor et al., 2007). The projections also indicate that there will be a large reduction in rainfall towards the end of the dry season. This implies that it will be necessary to develop adaptation strategies to deal with the changing conditions. Such strategies might include improved water storage and irrigation facilities, the development of drought tolerant varieties and diversification into suitable non-rice crops.

Rice production in low lying coastal areas is prone to damage caused by flooding and salinity. In Bangladesh, about 1.6 million farm families live in the coastal saline areas and are highly vulnerable to climatic extremes. The incursion of saltwater from the Bay of Bengal to inland areas is likely to be compounded in the future by the reduced flow of water in rivers during the dry season. Breeding for tolerance to salinity is being carried out at the International Rice Research Institute and in several national breeding programmes in Asia.

In conclusion, increasing temperatures will lead to greater heat stress and an increased risk of spikelet sterility in rice. Rice is currently grown in some extremely hot environments and there is a large genetic pool for heat resistance which can be exploited by rice breeders. Nevertheless, it will take time before new varieties with suitable characteristics are available. Meanwhile, some projections suggest that increased temperature will lead to a significant reduction in the growing season for Basmati rice in the Indo-Gangetic plain and this will have an adverse effect on yield. In Mali, yields of summer rice may also be reduced due to higher temperatures. At present there is little Fairtrade rice produced in areas likely to be affected by increased coastal inundation so this may not have a large impact.

3.4.2 Cotton

Cotton (*Gossypium* spp.) has a wide geographical range, but most of the production globally is concentrated in arid and semi-arid environments. The minimum temperature that will support the continued growth and development of cotton is 12–15 ^{O}C and the optimum temperature range is 20–30 ^{O}C (Reddy et al., 1997, Reddy et al., 1998). In some locations, such as southern Australia, cool temperatures are a limiting factor for cotton production. Low temperatures restrict plant growth and, when combined with high moisture levels, encourage the development of soil-borne pathogens which cause damping-off of seedlings.

Long staple cotton varieties, belonging to the *G. barbadense* species, are mainly grown in Egypt and Sudan as they need a long growing season to develop full staple length. Upland, medium-staple varieties belonging to the genus *G. hirsutum*, are more widely grown. Indeterminate types which continue to fruit over a relatively long period are selected for use in locally adapted cotton varieties. This trait contributes to yield stability under variable climatic conditions by making the plant better able to withstand periods of stress.

Cotton has a long flowering period during which successive cohorts of bolls are produced. Fibre length is determined during the early stages of the boll period, whereas fibre strength and micronaire[9] are determined during the later stages. Thus, fibre quality is influenced by the effects of

[9] Micronaire is a measure of the maturity and fineness of cotton fibre

temperature, and other variables such as available moisture, over a considerable period. Cool temperatures, especially low minimum temperatures, are known to result in reduced fibre strength and length but this effect varies among varieties. In southern Australia, the optimum sowing dates for yield and date to maturity are sub-optimal for fibre quality due to cool temperatures during flowering (Yeates et al., 2010).

High temperatures also adversely affect production. Soil temperatures of 38 °C and above were found to be harmful for seedling emergence (Nabi & Mullins, 2008). Root and shoot growth of seedlings were found to be faster at 32 °C than at either 20 or 38 °C. This is consistent with data from another study which shows that higher temperatures reduce the time taken for seedlings to emerge after sowing and the number of days from crop emergence to maturity (Yoon et al., 2009). However, in general, cotton is able to produce high yields under high radiation and high temperature provided water is not limiting.

Wang and co-workers (2008) analysed historical climate data and growth parameters of spring cotton between 1983 and 2004 in north-west China. During this period maximum and minimum temperatures increased with the largest increase recorded in the latter. They found that the length of time from seedling emergence to boll opening shortened. By contrast, the period of growth from boll opening to crop maturity was prolonged. Cotton yields increased and this was attributed to the warmer temperatures during the vegetative stage of the crop.

Some work has been done to assess varietal tolerance to high temperatures but little variation has been found among upland cotton varieties. Pima cotton varieties are generally less tolerant of high temperatures, but some varieties are able to minimize adverse effects through transpirational cooling (Reddy et al., 2000).

Several studies have looked at interactions between temperature and CO_2 on cotton growth and yield. Reddy and co-workers (2005) showed that, at a temperature of 26 °C, photosynthesis in individual leaves increased with higher amounts of atmospheric CO_2, up to 700 μL CO_2 L^{-1}. This positive response to elevated CO_2 increased at higher temperatures, up to 36 °C. At the canopy level, the highest response to elevated CO_2 was found to be at 34 °C.

Yoon and co-workers (2009) investigated the response of cotton plants to elevated CO_2 over different crop growth stages and at different temperatures. They found that, with higher than ambient levels of CO_2, the above ground biomass and the boll weight of cotton increased. This effect was more pronounced at the higher of the two temperatures tested (35/25 °C compared with 25/15 °C). Model projections of future cotton yields in Mali did not predict increases but they indicated that yields are not likely to be adversely affected by higher temperatures and increased levels of atmospheric CO_2 (Butt et al., 2005).

In conclusion, the available evidence from experimental work conducted on cotton suggests that elevated levels of CO_2 are likely to favour increased canopy growth. Provided temperature is not limiting and adequate water is available, this enhanced growth will result in higher yields. Where average temperatures are above around 30 °C, yields are likely to decrease due to poorer fruit retention. Faster rates of plant growth will not necessarily lead to higher uptake of water due to reduced leaf transpiration rates.

In Central Asia, for example in Kyrgyzstan where Fairtrade cotton is grown, modifications to crop management practices may be needed to conserve water and reduce soil degradation in order to guarantee sustainable production. A change from surface furrow irrigation to sprinkler or drop irrigation greatly improves the efficiency of water use. The use of minimum and zero tillage practices can lead to a significant increase in cotton yield in wheat-cotton rotations when compared with conventional ploughing techniques (Thomas, 2008).

3.4.3 Vegetables

A large number of crops are classified as vegetables and the wide diversity of crop types makes it difficult to summarise the potential effects of climate change on growth and yield. Few studies on likely impacts of climate change on vegetables have been carried out. Moreover, varietal differences may be large so that it is difficult to generalize from the results of some experiments.

In a review of the available literature, Peet & Wolfe (2000) concluded that higher levels of $C0_2$ are likely to benefit most crops, provided temperatures are not limiting. However, they suggested that the effects of increasing temperatures are much more complex to predict. Some vegetable crops such as tomato and pepper are extremely sensitive to high temperatures during the reproductive phase. Tomato plants are particularly vulnerable to heat stress during the period immediately before flowering when pollen release can be affected and pollen function impaired (Peet et al., 1998).

Under certain conditions, higher temperatures may lead to improved seed germination. For example, germination rates may increase in direct seeded crops such as leafy vegetables grown in cool seasons. Another potential benefit of a warmer climate in cooler regions is that the cropping season will be extended and it may be possible to grow an additional crop in some locations. On the other hand, crops such as celery which need a cold period to produce seed the following season may suffer reductions in yield and quality through warmer winters.

The quality of many vegetable crops is adversely affected by high temperatures and this may reduce the marketability of produce. For example, the sugar content in peas is reduced under high temperatures; this may be due to increased respiration during warm nights or to the shorter period over which the crop develops. High temperatures and long days induce flowering in some crops such as lettuce and spinach and the quality of the produce declines once this process has started. Some varieties are less susceptible to this flowering trigger, known as ‘bolting’, so farmers can make use of this as an adaptation strategy. In some locations, however, production areas may need to shift in order to sustain viable production.

Varietal differences in susceptibility to high temperatures may be large but breeding for heat tolerance in vegetable crops can be a complex process. For example, high temperatures can reduce yield by affecting factors such as the sprouting of seed tubers, growth rates and tuberization and each of these factors may be controlled by different genes (Peet & Wolfe, 2000). There may also be secondary effects that need to be considered; for example, high temperatures influence susceptibility to certain diseases.

In view of the wide variety of crops and production systems it is not possible to generalise the likely impacts of climate change on vegetable production. However, it is clear that for some crops such as tomato, eggplant and pepper the risk of adverse effects from exposure to heat stress will increase and this will have a negative impact on yields. In areas where there is a heavy reliance on supplementary irrigation greater variability in rainfall will affect production. For example, green beans grown in Kenya and Uganda require differing amounts of irrigation depending on the location and the rainfall pattern in a particular year. In some areas competing demands for water or the absence of an adequate water distribution system may make green bean production an increasingly marginal activity.

3.4.4 Coffee

Woody perennial species, which include crops such as coffee, cocoa and tea, have lower photosynthetic rates than most annual crops. This has implications for their ability to respond to changing climatic conditions. In addition, several tropical tree crops, including coffee (genus *Coffea*), are prone to photoinhibitory damage under conditions of high radiation, especially when combined with water shortage. They also have large root resistances to water uptake which results in early stomatal closure, reducing their ability to absorb CO_2.

Coffee is grown in the inter-tropical zone, between 25° N in Hawaii and 24° S in Brazil, and this range is determined primarily by climatic conditions; in particular, by favourable temperature and humidity (Smith, 1989). Optimal temperatures for both Arabica and Robusta types vary according to the crop growth stage, but each type has a mean temperature range to which it is best suited. Arabica coffee, which has its origins in tropical forests in Ethiopia at altitudes of 1600–2800 metres above sea level, grows most successfully in areas with a mean average annual temperature of around 20 ^{O}C. However, some modern varieties are grown in northeastern Brazil at mean temperatures as high as 24–25 ^{O}C (DaMatta & Cochicho Ramalho, 2006). Robusta coffee, which is native to lowland equatorial forest in the Congo river basin, produces adequate yields within a mean temperature range of around 22-30 ^{O}C.

Low temperatures have a serious impact on both Arabica and Robusta coffee and frost may kill the coffee tree. Further warming will mean that coffee can be grown at more northerly and southerly latitudes. For example, the risk of frost will reduce in parts of Brazil making these areas more suitable for coffee production. However, there is another limit to the latitudinal range of the crop as it is also susceptible to changes in photoperiod. Drought is a more frequent problem than frost and has a much larger impact on coffee production. Annual rainfall of 1200–1800mm is optimal but a dry period is required to stimulate flowering.

Although it is difficult to verify the causes, there is some evidence that coffee production is being affected at lower altitudes. In a low altitude production area in Costa Rica, for example, coffee yields have been significantly reduced by higher mean and maximum temperatures (Fournier & Di Stefano, 2004 cited in Baker & Haggar, 2007). Moreover, in India there has been a gradual shift from the higher quality Arabica to Robusta types. It is likely that this change has been influenced, at least in part, by adverse impacts on quality and by the greater ability of Robusta to withstand warmer conditions. Higher altitudes will become more suitable for production of high quality types but factors such as soil type, infrastructure and regulations on its use will constrain the expansion of the crop into these areas.

Recent research being carried out in Central and South America suggests that, overall, the area of land suitability for the cultivation of coffee will be significantly reduced by 2050. Areas where coffee is currently grown at lower altitudes will no longer be suitable and farmers will need to switch to alternative crops (Jarvis et al., 2009). There will also be a reduction in the amount of land suitable for the production of Arabica coffee. An extrapolation of recent temperature trends in Mexico to 2020, has resulted in a prediction of a 34 percent yield decline and a decrease in net profit from US$200 to US$20 per acre (Gay et al., 2006). Similar projections have been made for coffee growing regions in East Africa. In Kenya, it is anticipated that lower rainfall in the dry season and an increase in temperature will make coffee production unviable at altitudes of around 1300 metres (CIAT, 2010).

Because of its vulnerability to high levels of radiation, growing coffee under shade is usually advantageous (Lin, 2010). Shading also creates a more favourable microclimate which buffers air humidity and soil moisture availability, thereby prolonging the period of leaf gas exchange. Shade trees are pruned in order to control the amount of light reaching coffee plants in the understorey, so that coffee yields are not substantially reduced. Mulching coffee plants with the prunings has several benefits, including improved moisture retention, lower rates of soil erosion and reduced competition from weeds.

Another advantage of shading is that it can reduce the impact of certain pests and diseases. The results of a modelling approach in which laboratory experiments were related to temperature trends suggested that the coffee berry borer, *Hypothenemus hampei*, will become more important in areas where mean temperature increase (Jaramillo et al., 2009). This is likely to be less evident in East Africa where the presence of a distinct dry season limits the number of generations of the pest which needs berries for its development. In some countries in Latin America, such as Colombia, where rainfall is more evenly distributed flowering takes places over a much longer period and this favours the proliferation of the borer. The abundance of the pest is lower under shade trees, possibly due to larger numbers of natural enemies, and so (Teodoro et al., 2008).

The practice of pruning shade trees has the disadvantage of reducing the amount of carbon sequestered in plant biomass. However, when prunings of certain tree species are used as mulch this loss of carbon can be at least partially offset by increased carbon sequestration in soil organic matter. In field experiments carried out in Hawaii, it was found that the use of *Leucaena* spp. as shade trees increased levels of carbon and nitrogen in the soil (Youkhana & Idol, 2009).

In recent decades there has been a trend in some regions towards removing shade trees in coffee and converting plantations to full-sun production (Lin 2010) because of the short-term productivity gains and reduced labour costs. This trend will need to be reversed in order to reduce the vulnerability of coffee growers to increased temperatures and reduced water resources.

In general, in many coffee-growing regions a combination of lower rainfall and higher temperatures will render production unsustainable by 2050, at lower elevations where the crop is currently cultivated. Farmers will need to make more use of shade trees, select drought-resistant varieties and use supplementary irrigation. Higher altitudes, where it is currently too cold to grow coffee, will become more suitable but available land is usually scarce and the environment highly fragile.

3.4.5 Cocoa

Cocoa (*Theobroma cacao*) is a tropical species with a narrower geographical range than coffee. Cocoa trees will grow between 20^0 N and S, but the majority of production is concentrated at elevations below 300m or so within 10^0 N and S (Purseglove, 1968). The bulk of cocoa production is in Africa, mainly in Côte d'Ivoire and Ghana, which accounted for 70 percent of global production in 2008/09 (ICCO, 2010). Cocoa trees yield well under relatively high temperatures, with maximum and minimum mean annual temperatures of 30–32 ^{O}C and 18–21 ^{O}C, respectively. Cocoa is sensitive to soil water deficiency and yields are more affected by rainfall than by any other environmental factor. Optimum annual rainfall is 1500–2000mm and yields are reduced when monthly rainfall of less than 100mm occurs over more than three successive months.

In Ghana, farmers believe that rainfall patterns during the past decade have been highly variable and that periodic droughts have led to high seedling mortality and low yields (Anim-Kwapong & Frimpong, 2004). Attempts to replant degraded cocoa plantations have been constrained by poor plant establishment caused by droughts. Rehabilitation efforts have also been affected by other factors such as damage by capsid bugs which are a particular problem when moisture deficits are high. These problems are likely to be compounded in the future, as lower rainfall levels have been predicted for the evergreen rainforest zone; -3% by 2020, -12% by 2050 and -20% by 2080 (Anim-Kwapong & Frimpong, *ibid*). Highly variable rainfall patterns can also increase the risk of losses from excessive rainfall. In Ghana, black pod disease is favoured by damp conditions and is particularly prevalent when there is unusually high rainfall during the short dry period in July and August.

As with coffee, cocoa grows well under shade and the use of shade trees will be important to ensure sustainable production under changing climatic conditions. Trials carried out in Ghana have shown that several *Albizia* species have the characteristics needed to be effective as shade trees in degraded forest areas where replanting of cocoa is taking place (Anin-Kwapong, 2003). These trees are fast-growing, have a high leaf nitrogen content and are responsive to coppicing.

But there are constraints to the adoption of systems using shade trees in cocoa production. A study carried out in Ecuador indicated that, although the traditional shade-grown variety 'Nacional' is longer-lived and has a better flavor than modern full-sun varieties, farmers are switching to the modern varieties because of their higher yields early in the production cycle (Bentley et al.;, 2004). In parts of Asia in particular, increasing labour costs mean that 'full-sun' production of cocoa is cheaper than systems involving shade trees and financial incentives may be needed to maintain shade trees (Franzen & Mulder, 2007).

In Ghana, farmers are also removing shade trees in order to exploit short term production gains. However, in the absence of adequate fertilizer inputs these initial yield gains cannot be sustained over long periods. The removal of shade trees is reducing soil fertility and also exposes trees to higher incidence of attack by capsid bugs (Anim-Kwapong & Frimpong, *ibid*).

In summary, the main threat to cocoa production posed by climate change lies in the increased susceptibility of trees to drought. This is a particular concern in West Africa where the adverse effects of high variability in seasonal rainfall patterns is already a constraint to cocoa yields.

3.4.6 Tea

The geographical range of tea (*Camilla sinensis* L.) is 49^O N (Carpathians) to 30^O S (South Africa). Tea is grown at altitudes of up to 2700 metres in Kenya and Rwanda (Owuor et al., 2010). Yields of tea decline with increasing altitude due to slower growth of the plants. It has been estimated that in Kenya there is a reduction in yield of 1 kg ha^{-1} of made tea for every 100m increase in altitude (Othieno et al., 1992). The slower growth of tea plants at higher altitudes leads to improved quality, as exemplified by Darjeeling tea. However, there are large differences between tea varieties in the manner in which they respond to changing environmental conditions, including differences in altitude (Owuor et al., *ibid*).

Tea plants are highly susceptible to drought and will not thrive well when moisture is limiting. Field experiments carried out in southern Tanzania showed that drip irrigation increased yields and gave better results than overhead sprinkler irrigation (Kigalu et al., 2008). Drip irrigation also results in substantial savings in water and labour compared to overhead sprinkler irrigation (Möller & Weatherhead, 2007; Kigalu et al., 2008). Although the benefits of drip irrigation have been demonstrated widely in recent years, uptake of the technology is still limited in many locations. Work is continuing in Tanzania to identify how low cost drip irrigation kits can be extended to smallholder tea growers.

In Sri Lanka, concerns have been expressed about the likely adverse impacts on climate change on tea production (Wijeratne, 1996). Tea plantations are considered to be especially vulnerable due to the large-scale removal of shade trees which has taken place over several decades and the high level of soil erosion in upland plantations. As tea production is overwhelmingly rainfed, adaptation options through improved water management are currently quite limited.

Concerns have been expressed that malaria epidemics are increasing in upland areas, including tea plantations, as a result of increasing temperatures. However, assessments of the available evidence suggest that any increase in malaria incidence, at least until 1996, is not linked to temperature changes (Shanks et al., 2002). Reiter (2008) concludes that increased malaria incidence on tea estates in the Kenya Highlands is mainly attributable to growing resistance to anti-malarial drugs and not to climate change. However, if the period during which mean monthly temperatures remain above 18 ^{O}C, the critical threshold for mosquito survival, is extended significantly in the future this may well lead to an increase in the transmission of malaria.

As with coffee and cocoa, the probability of increased variability in rainfall will increase the vulnerability of tea plants to drought stress. In East Africa, tea production is likely to become less viable at the lower levels of its current altitudinal range within the next few decades. A reduction in quality is also likely to occur in some varieties as temperatures increase at higher altitudes.

3.4.7 Banana

Bananas and plantains (Musa species) are grown under a wide diversity of agro-climatic conditions. Cultivation systems vary considerably according to the physical environment and whether production is large-scale and commercial or for local markets or subsistence (Robinson, 1995). In the subtropics and areas with a Mediterranean climate, temperature has a major influence on the suitability of areas for banana production. Minimum temperatures below 10 ^{O}C and maximum temperatures above 38 ^{O}C prevent plant growth and cause physiological problems (Samson, 1980). However, through modifications in crop management it is possible to grow bananas successfully at peak summer temperatures of 40–45 ^{O}C in Western Australia and at temperatures of 1–8 ^{O}C during the winter in Israel. In the humid tropics temperature is not a limiting factor for banana production.

Bananas need large quantities of water for optimal growth and yield. It has been estimated that in the tropics banana plantations take up between 900mm and 1800mm of water during the ten month period from planting to harvest (Stover & Simmonds, 1987). As banana is a very shallow–rooted crop, it is important that water is available continuously throughout the growing period. Supplementary irrigation is needed in some production areas in Latin America, including Honduras and Ecuador where annual rainfall is high but is insufficient to meet the requirements of the banana crop for about four months of the year. As some regions become drier in the future, the need for supplementary irrigation will increase in the tropics and in subtropical areas of banana production such as Australia and South Africa. Drip irrigation systems are becoming increasingly popular as these are more efficient than sprinklers. Although drip irrigation systems only wet a portion of the root zone, this does not seem to have an adverse effect on plant growth. On the other hand, sprinkler systems have an advantage when temperatures are very high as they can reduce heat stress in plants through evaporative cooling (Robinson & Alberts, 1989).

In some areas of production where annual rainfall exceeds 2500mm per year, such as in Costa Rica, the provision of suitable drainage and soil conservation measures is important for adequate root growth and fruit yield and for sustainable production. Such measures are also important in areas where there are heavy rainfall events over short periods and where bananas are grown on slopes; for example, in the highlands of East Africa. The use of drainage and soil conservation measures will be increasingly important if there is a greater frequency of heavy rainfall events in the future, as predicted in some global climate models. The challenge is to understand the motivations for farmers to use soil conservation measures and to find suitable ways to support more widespread adoption (Mbaga-Semgalawe & Folmer, 2000).

Wind damage can be an important constraint to yield in some regions. This was demonstrated in field trials in Nigeria in which optimum yields were obtained when planting was done in December. Yields from later plantings were reduced by around 25% as a result of wind damage to banana plants maturing during the windy dry season (Obiefuna, 1986). Greater consideration may need to be given to the risk of wind damage in such areas in the future, especially if, as predicted, there is an increased frequency of storm events.

The possible increased risk of storm damage to banana plantations in the Caribbean is an area of concern for the future. An analysis of the causes of an increase in hurricane activity in the Atlantic since 1995 suggests that increases in local sea surface temperature were responsible for 40%t of this increase (Saunders & Lea, 2008). The study did not seek to determine whether the warming was caused by an increase in greenhouse gases. But the establishment of a link between sea surface temperature and hurricane activity suggests that more attention needs to be given to examining these effects and reviewing their use in forecasting systems.

Bananas are particularly susceptible to epidemics of diseases because modern cultivars have a very narrow genetic base. The effects of this were seen in the middle of the 20th century when devastating outbreak of Panama disease, caused by the Fusarium wilt pathogen, wiped out large areas of the widely cultivated, but highly susceptible cultivar, 'Gros Michel'. Concerns have been expressed about the reliance on cultivars in the Cavendish subgroup for the export trade; particularly on its potential vulnerability to Black Sigatoka disease, caused by *Mycosphaerella fijiensis.* However, risk analysis based on matching disease distribution maps to outputs from global climate models suggest that, overall, the area favourable for the development of Black Sigatoka will decrease (De Jesus et al. 2008; Ghini et al., 2008). Nevertheless, substantial areas will remain conducive to the occurrence of the disease and Black Sigatoka control strategies will continue to be essential components of banana crop management systems.

In conclusion, changes in rainfall patterns are likely to have a larger effect on banana production than increases in temperature. In countries in Central and South America where Fairtrade bananas are grown areas which currently have unstable rainfall during drier periods will become increasingly marginal for sustainable production. Increased attention will need to be given to water use efficiency, especially through the wider use of drip irrigation systems. In the Caribbean, the major threat will be from the greater prevalence of storm damage from increased hurricane activity.

3.4.8 Sugar cane

Sugar cane (*Saccharum officinarum*) is generally considered to be a tropical crop, but it is also grown successfully in subtropical areas between around 30° N and 30° S, and from sea level to altitudes of approximately 1000m (Blackburn, 1984). The minimum temperature for active growth is around 20 ^{O}C. Optimum mean daytime temperatures are around 30 ^{O}C and yields are greatest with high amounts of incident solar radiation. Cooler and drier conditions are needed for ripening and harvesting; otherwise, sucrose yields decline significantly (Blackburn, *ibid*).

As sugar cane has a relatively long growing season, the crop experiences a wide range of environmental conditions in certain locations. In some sugar cane regions such as Argentina, South Africa, and the USA frost damage may be a serious yield constraint. Little research has been done on the effect of high temperatures, but sugar cane plants start to be stressed at temperatures above 35 ^{O}C even when adequate moisture is available (Blackburn, *ibid*). Temperatures above 38 ^{O}C lead to a reduction in the rate of photosynthesis and an increase in respiration leading to a virtual halt to plant growth.

Concerns have been expressed about the future sustainability of sugar cane production in the Mpumalanga and Kwazulu Natal districts of South Africa where further increases in temperature and reductions in rainfall may force farmers to switch to more heat tolerant crops (Gbetibouo & Hassan, 2005). However, in some other areas climate change may lead to increased productivity. A recent projection for Brazil indicates that the area planted to sugar cane will rise significantly until 2030 and that mean crop yield should increase by 7% from 77 to 82 t ha^{-1} (De Souza et al., 2009).

In general, at least 1200mm of rainfall per year is needed to produce sugar cane, although Blackburn (1984) gives several examples of where crops have survived under drier conditions. Tolerance to drought is favoured in soils which allow deep rooting and plants vary in their susceptibility to drought at different growth stages. Results from field trials carried out in Australia indicate that sugar cane can tolerate early season water deficits quite effectively, partly through the plant's ability to produce new shoots (Robertson et al., 1999). However, once the crop canopy has become well established shortage of water will lead to reduced plant growth and a reduction in sucrose yield in stalks.

Unusually for a C_4 crop, there is some evidence that susceptibility to drought may be mitigated to a certain extent by enhanced levels of CO_2. In pot experiments (De Souza et al., 2008) and under simulated field conditions in greenhouses (Vu & Allen, 2009) elevated CO_2 resulted in increases in photosynthesis and plant biomass. In the latter study, an increase in water use efficiency was reported at 720 (compared with 360) μmol mol^{-1} CO_2. The authors suggested that the improvement in the plant water status would allow plants to continue active photosynthesis for at least an additional day under drought conditions (Vu & Allen, *ibid*).

Changed climatic conditions may make sugar cane plants more susceptible to damage from some pests and diseases. Although conclusive evidence is lacking, there are indications that the highly damaging red rot disease, *Colletotrichum falcatum*, spreads more rapidly at temperatures above around 37 ^{O}C.

Overall, the available evidence on the potential impacts of climate change on sugar cane production suggests that, whilst enhanced levels of CO_2 may enhance plant growth the apparent benefits will not be seen when temperature is limiting. Thus, in countries such as Brazil there may be yield gains, but these are unlikely to occur in countries such as Malawi and South Africa where temperatures exceed the mid-thirties degrees centigrade.

3.5 Summarising the evidence

The scientific literature review provides evidence which suggests that climate change will have varying impacts on different Fairtrade crops and that these impacts will also be strongly influenced by location. Current projections indicate that, where moisture is not limiting, yields of cotton and sugar cane will not be significantly affected. In some countries, such as Brazil, sugar cane yields may actually increase. By contrast, production of coffee and tea will become unviable in some areas due to the combined effects of increased temperature and longer periods of drought.

Some Fairtrade crops are likely to be vulnerable to the projected increased frequency of extreme events. High temperatures for even very short periods during flowering can cause substantial yield loss in rice. Concentrated periods of unusually heavy rainfall will have adverse effects on tree crops and bananas, unless adequate soil conservation measures are in place. Extended periods of rainfall may also reduce yields; for example, through favouring increased incidence of disease in cocoa. Consideration also needs to be given to the potential impacts of increased wind damage, particularly on banana and sugar cane in the Caribbean.

4. Assessing the projected climate change impacts on key Fairtrade countries

4.1 Projected climate change impacts

This section summarises readily available climate projections for countries producing Fairtrade products. Table 1 lists, by region and alphabetically within regions, all countries either recording Fairtrade production or having registered Fairtrade producers (2007 figures provided by the Fairtrade Foundation). For each country, the Fairtrade commodities for which that country is in the top three producers worldwide are listed in column 2. Other Fairtrade commodities produced in that country (or for which there are registered producers) are listed in column 3.

Climate data and climate change projections have been produced in a summarised form for 52 developing countries by UNDP (see **http://country-profiles.geog.ox.ac.uk**). These include 12 Fairtrade producing countries in Africa, seven in the Caribbean/Central America, plus Vietnam (all indicated in the last column of Table 5), but none in mainland South America, nor other Asian countries.

The UNDP profiles include projections for the 2030s, 2060s and 2090s, using 15 different General Circulation Models (GCMs) and three emissions scenarios (SRES scenarios A2, A1B and B2).[10] Tables 6 and 7 give a much abbreviated summary for these 20 countries. Table 6 present projections of changes in mean temperature and mean precipitation for the 2030s. We considered that while trends are clearer in the later decades, the complicating factors of non-climate trends and the evolution of Fairtade itself were greater, and the relevance to Fairtrade policy and practice less. Ranges given are the minima and maxima of all combinations of 15 models and 3 scenarios.

Trends in overall rainfall and seasonal distribution of rainfall, which become clearer for the 2060s, are presented in tables in annexes 2 and 3. These tables also present the frequency of hot days and hot nights, and percentage of rainfall falling in heavy rainfall events. These are not available for the 2030s and are given here for the 2060s. Frequency of hot days and hot nights may be significant for plant development, while heavy rainfall events will have significance for soil and water management, for some plant diseases and pest outbreaks, and for the maintenance of infrastructure like roads. A "hot day" is defined as a day whose maximum temperature would place it in the top 10% of days in the reference period 1970–99. A 'hot night' is defined as a day whose minimum temperature would place it in the top 10% of days in the reference period 1970–99. Heavy rainfall events are defined as the heaviest 5% of rainfall events in the region, and changes as percentages of total rainfall in heavy events in the reference period 1970–99.

Further definitions and technical background are given at **http://country-profiles.geog.ox.ac.uk/UNDPCCCP_documentation.pdf.**

The country profiles do not deal with projected year-on-year variability, which will be important for droughts, or with other parameters such as wind (other than tropical storms) which may be important for dispersion of pests and diseases, and are giving an overall average change which could differ considerably from what will happen, for example in the tea or coffee growing region of each country. Therefore, the impacts noted may be of greater severity than can be reported in the present document.

It is also important to explain that country-level climate projections, even before recognising divergence between models and emissions scenarios, cannot be used in any straightforward manner to project impacts on particular crops. Far more information will be needed on current climates and microclimates in areas where crops are grown, many of which are altitude-related and thus change significantly over small distances (particularly for tea and coffee). However, it is necessary to begin with the national level data as this is the level at which most existing analyses are still being made.

[10] The A1B scenario is for rapid economic growth *and* economic convergence between regions, with population stabilising around 2050 and with a balance of energy sources. The A2 scenario is for a more regionalised world, with more rapid population growth. The B2 scenario is for a regionalised, but more ecologically friendly world. Each has different implications for total GHG emissions and models are therefore run separately for each scenario.

Table 5 Fairtrade Producer Countries & UNDP profiles

Country	Commodities for which country is in top 3 FT producers worldwide	Other FT commodities produced	UNDP CC Country Profile
Africa			
Benin		F&V[11]	✔
Burkina Faso		Cotton, F&V	
Cameroon	Cotton	Coffee, Cocoa	✔
Congo		Coffee	
Cote d'Ivoire		Coffee, Cocoa, F&V	
Egypt	F&V	Tea, Cotton, Rice	
Ethiopia		Coffee	✔
Ghana	Cocoa	Bananas, F&V	✔
Kenya	Tea, Flowers	Coffee	✔
Malawi	Sugar	Tea	✔
Mali	Cotton	Rice, F&V	✔
Mauritius		Sugar	✔
Namibia		F&V	
Rwanda		Coffee, Tea	
Senegal		Cotton, F&V	✔
Sierra Leone		Cocoa	
South Africa	F&V	Tea	
Tanzania	Flowers	Coffee, Tea	✔
Togo		F&V	
Uganda		Coffee, Tea	✔
Zambia		Coffee, Sugar	✔
Zimbabwe		Flowers	
Caribbean/Central America			
Belize		Cocoa, Sugar	✔
Costa Rica		Coffee, Bananas, Sugar, F&V	
Cuba	F&V	Sugar	✔
Dominican Republic	Cocoa, Bananas	Coffee, F&V	✔
El Salvador		Coffee	
Guatemala		Coffee	
Haiti		Coffee, Cocoa, F&V	
Honduras		Coffee	

[11] Fruit and vegetables

Table 5 (continued)

Country	Commodities for which country is in top 3 FT producers worldwide	Other FT commodities produced	UNDP CC Country Profile
Caribbean/Central America (continued)			
Jamaica		Bananas	✔
Mexico	Coffee	Cocoa, F&V	✔
Nicaragua		Coffee, Cocoa	✔
Panama		Cocoa, Bananas	
Windward Islands[12]	Bananas	F&V	✔
South America			
Argentina		F&V	
Bolivia		Coffee, Cocoa	
Brazil		Coffee, Cotton, F&V	
Chile		F&V	
Colombia	Coffee	Cocoa, Bananas, Flowers	
Ecuador	Bananas, Flowers	Coffee, Cocoa, Sugar	
Paraguay	Sugar		
Peru	Coffee, Cocoa	Tea, Bananas, Cotton, Sugar, F&V	
Asia			
China		Tea	
East Timor		Coffee	
India	Cotton, Rice	Coffee, Tea, Cocoa, Flowers	
Indonesia		Coffee	
Kyrgyzstan		Cotton	
Laos		Coffee, Tea	
PNG		Coffee	
Philippines	Sugar		
Sri Lanka	Tea	Flowers	
Thailand	Rice	Coffee	
Vietnam		Coffee, Tea	✔

[12] The term 'Windward Islands' is used in trade figures to aggregate trade or production from Dominica, St Lucia, and St Vincent & The Grenadines. There are separate Profiles for each of these countries.

Table 6 Country-level climate projections for 2030s

Country	Commodities for which country is in top 3 FT producers worldwide	Other FT commodities	Observed mean temp. (°C)	Changes in mean temp. by 2030s (°C)	Observed mean precn. (mm/month)	Changes in mean precn. by 2030s (%)
Africa						
Benin		F&V	26.8	0.6 – 1.7	88.1	-9 - +6
Cameroon	Cotton	Coffee, Cocoa	24.1	0.6 – 1.7	129.7	-2 - +4
Ethiopia		Coffee	22.7	0.5 – 1.6	65.6	-4 - +16
Ghana	Cocoa	Bananas, F&V	26.6	0.9 – 1.7	98.0	-9 - +8
Kenya	Tea, Flowers	Coffee	23.9	0.5 – 1.5	57.3	-2 - +17
Malawi	Sugar	Tea	21.7	0.5 – 1.8	91.7	-14 - +10
Mali	Cotton	Rice, F&V	27.9	0.8 – 2.2	27.2	-13 - +23
Mauritius		Sugar	24.3	0.3 – 1.3	132.4	-12 - +14
Senegal		Cotton, F&V	27.8	0.6 – 1.7	57.2	-19 - +22
Tanzania	Flowers	Coffee, Tea	22.2	0.5 – 1.3	85.0	-6 - +13
Uganda		Coffee, Tea	22.0	0.5 – 1.7	96.3	-7 - +14
Zambia		Coffee, Sugar	21.3	0.6 – 1.8	80.6	-9 - +10
Central America/Caribbean						
Belize		Cocoa, Sugar	24.9	0.4 – 1.7	172.7	-34 - +15
Cuba	F&V	Sugar	25.7	0.4 – 1.3	104.7	-22 - +9
Dominican Republic	Cocoa, Bananas	Coffee, F&V	25.1	0.3 – 1.2	111.4	-28 - + 18
Jamaica		Bananas	26.0	0.3 – 1.3	155.2	-35 - +17
Mexico	Coffee	Cocoa, F&V	20.8	0.5 – 1.5	61.7	-18 - +8
Nicaragua		Coffee, Cocoa	25.2	0.3 – 1.7	186.5	-30 - +18
Windward Islands	Bananas	F&V				
Dominica			25.2	0.3 – 1.2	255.4	-17 - +17
St Lucia			26.4	0.3 – 1.2	179.2	-25 - +18
St Vincent			26.6	0.3 – 1.2	142.7	-24 - +14
Asia						
Vietnam		Coffee, Tea	23.5	0.3 – 1.4	143.2	-9 - +8

Source: Figures provided by Fairtrade Foundation, UNDP Climate Change Country Profiles

The most obvious lesson from the tables is the considerable degree of uncertainty that exists about country-level impacts of climate change, once multiple scenarios for worldwide greenhouse gas emissions, and multiple climate models, are used. All countries show significant warming by the 2030s, but for each country some combinations of emission scenario and climate model at the lower end of the range keep estimates of temperature increase below 1°C. The extreme value of 2.2 °C for Mali under scenario A1B should be noted. By the 2030s no trends *in differential warming* between regions of each country, or seasons of the year, are visible. However, the large variation in baseline temperatures, particularly in countries with large altitude ranges like Kenya[13] will mean that the effects of warming may show great regional variation[14]. This regional variation and the diversity of 'starting point' vulnerability in different contexts means that recommendations for adaptation cannot be broad-brush but will need to involve local processes of learning and innovation, although these can draw on best bets and lessons from elsewhere of course.

Estimates of increases and decreases in rainfall by the 2030s are similarly spread with both increases and decreases projected for each country. Projections are more likely to be for increases in countries of East Africa and decreases in Central America/the Caribbean. For Cameroon, Ethiopia and Ghana, there is a more evident trend towards drying in the north of each country. Some patterns of differential changes in precipitation by season are evident. These become clearer by the 2060s, as shown in Annexes 2 and 3, although the summaries there of *most likely* precipitation changes (generally speaking, agreements between the medians of model ensembles for each of the emissions scenarios) do not express the full range of uncertainties in the model outputs.

Annexes 2 and 3 also show that for all model-scenario combinations for all countries the frequencies of hot days and hot nights relative to the present are likely to increase. Increase in hot days is more marked in Central America/the Caribbean (except Mexico) while increase in hot nights is very marked for some countries of each region, especially Uganda, with a maximum value of 84% hot nights. The percentage of rainfall falling in heavy events is generally projected to increase in Africa and Vietnam, and to decrease in Central America and the Caribbean

Four further factors are noted in the Profiles. For Central America/the Caribbean (other than St Lucia and St Vincent), Mauritius and Vietnam, the Profiles note that tropical cyclones are likely to become more intense under global warming, but that changes in frequency and in storm tracks show great uncertainty. Increased cyclone activity may lead to increases in wet-season rainfall above and beyond those projected by GCMs.

Secondly, for all countries except Cameroon, the Profiles note that "model simulations show wide disagreements in projected changes in the amplitude of future El Niño events" and that this contributes to uncertainty, especially in countries where the influence of the El Niño Southern Oscillation is strong – the African countries and Nicaragua.

Thirdly, for West African countries, the Profiles come with an additional caveat about the wide divergence between models on rainfall trends, the failure of existing models to reproduce 20th century inter-annual rainfall variability and the need for further research.

Fourthly, coastal regions of all but the landlocked countries will be affected by sea-level rise. Table 4 gives ranges for the projected rises for the 2090s; there are small variations for the region or ocean concerned. It is very unclear whether any current Fairtrade producing areas would be threatened by sea-level rises of these magnitudes: if they are it would presumably be rice production that would be threatened.[15]

Table 7 Projected sea–level rises for the 2090s, in metres above 1980–1999 levels

Scenario	Minimum	Maximum
B1	0.13	0.43
A1B	0.16	0.53
A2	0.18	0.56

4.2 Example country case studies

In order to explore in more detail the possible implications and areas of concern for Fairtrade commodities, we will look in more detail at current climate data and climate projections for three countries: Kenya, Mali and the Dominican Republic. These three countries were chosen because they are countries in which Fairtrade is highly active, they provide a good geographical spread, and they cover a diverse range of Fairtrade crops. Of course it may be useful for further analysis of available evidence to be conducted for other Fairtrade countries. Data and projection are drawn from the UNDP Profiles unless otherwise stated; implications for agriculture are our own.

4.2.1 Kenya

Kenya is the world's largest exporter of Fairtrade tea and Fairtrade flowers. It also has Fairtrade certified coffee producers, but as of 2007 Fairtrade export figures for coffee were not available.

Average temperatures vary little throughout the year, but considerably by altitude, with the highest regions having average temperatures of 15 °C, compared with 29 °C on the coast. Kenya has two distinct rainy seasons, the short rains in October–December and the long rains in March to May. In some areas there can be as much as 300mm rainfall in

[13] Or outside our sample, countries with large latitude ranges like Chile

[14] A general overall national level temperature increase or decrease does not necessarily show what will happen in specific areas of the country – many of the crops discussed here grow in niche environments and the changes in these niche environments could be very different to the projected national average changes particularly in very large and diverse countries.

[15] And possibly some banana-growing areas

a month. The Kenyan climate is strongly influenced by the El Niño Southern Oscillation - El Niño events usually cause increased rainfall in the short rains while La Niña events decrease rainfall.

Since 1960, mean annual temperature and frequency of hot days have increased, especially during the long rains. Frequency of hot nights has increased even more markedly, especially during the short rains.

Rainfall since 1960 does not show statistically significant trends. Well-publicised recurrent droughts have affected the drier, mainly pastoral, areas, but whether there has been a real increase in drought frequency or severity (as distinct from an increase in people's vulnerability to drought) is still open to debate.

Mean annual temperatures are projected to increase by 0.5 to 1.5 °C by the 2030s, and 1.0 to 2.8 °C by the 2060s. Hot days will increase to up to 45% of days by the 2060s, and hot nights even more quickly to up to 75% of nights.

Few et al. (2006) discuss likely drying and exacerbation of drought in the northern part of the country. The long-term projections presented in the UNDP Profile are for increased rainfall, without obvious differentiation between regions, and become more consistent for the 2060s and 2090s. Percentage of rainfall falling in heavy events will also increase.

The chief area of concern for Kenya's Fairtrade crops will be the effect of increased temperatures on tea and coffee. Because these are generally higher-altitude crops, effects will be location-specific. 1989 projections by UNEP[16] suggest a sharp decrease in areas suitable for tea cultivation with a temperature rise of 2 °C. Planting of shade trees and low-cost irrigation may be possible adaptations for smallholder tea and coffee growers in the face of rising temperatures[17].

As the second main Fairtrade export from Kenya, impacts on flower cultivation and possible adaptations need to be researched. Water access and availability will be a key issue for flowers in the future, but this could be exacerbated by climate change and by increased market and consumer awareness. Temperature effects should also be researched, although greenhouses/poly tunnels have more control over this, than sun grown situations.

Two impacts of climate change on other aspects of livelihoods may be felt by Fairtrade producers. The issue of the spread of malaria into the highland areas where tea and coffee are grown has already been discussed. Increased rainfall, percentage of rain falling in heavy events, and maxima of 1-day and 5-day rainfall events may cause floods, particularly given Kenya's varied topography.

4.2.2 Mali

Mali is the world's third largest exporter of Fairtrade cotton and exports much smaller amounts of Fairtrade fruit and vegetables. It also has Fairtrade certified rice producers, but as of 2007 Fairtrade export figures for rice were not available. Most of the Malian population is concentrated in the south of the country, with the north being extremely arid and sparsely populated, mainly by mobile pastoralists.

Mali has a single rainy season, peaking in August, with virtually no rainfall between November and March. Southern regions receive up to 300mm per month during the rains. Average temperatures across most of the country are 27-30 °C: in the south the rainy season (July–September) is slightly cooler and the dry season (April– June) slightly hotter.

Mean temperatures have increased since 1960. The frequency of hot nights has increased significantly for all seasons except December–February, but the frequency of hot days has not increased significantly.

Rainfall in Mali, as in other countries of the Sahel, is subject to strong inter-annual variability and decadal cycles. The late 1990s and early 2000s have been relatively wet, following the serious droughts of the 1970s and 1980s.

Mean annual temperatures are projected to increase by 0.8 to 2.2 °C by the 2030s, the strongest increase for any of the Fairtrade countries for which we have projections, and 1.2 to 3.6 °C by the 2060s. Rates of warming are similar for all seasons and all regions. Hot days will increase to up to 38% of days by the 2060s, most strongly in July–September although there are wide differences between models on this point, and hot nights to up to 40% of nights, also most strongly July–September.

The Sahel is one of the regions of the world with most uncertainty about long-term rainfall projections (Christensen et al. 2007), but the models for Mali tend towards decreases, especially in the southwest during July–September. There is a tendency towards an increase in the percentage of rainfall falling in heavy events, especially in October to November, for which there may also be increases in maxima for 1-day and 5-day rainfall events.

As already discussed, cotton in general has an optimum temperature range of 20–30 °C. Depending on region and season, projected temperature increases in parts of Mali are at risk of exceeding the upper limit within a relatively short time. However, a modelling exercise specifically for Mali (Butt et al. 2005) does not predict decreases in cotton yields.

Rice, as discussed above, is sensitive to within-day temperature variations, and this may be cause for concern in Mali, though increases in hot days and hot nights are not as marked as in some other countries. Fruit and Vegetable quality may be adversely affected by higher temperatures.

[16] **http://maps.grida.no/go/graphic/impact_of_temperature_rise_on_tea_in_kenya**. The early date and uncertain status of these projections is noted.

[17] More consideration is needed of whether 'low cost' irrigation can actually be achieved, particularly in quite steep and high tea and coffee areas, which may involve serious pump equipment and fuel requirements and pipes and storage tanks. There may be relevant examples from French bean irrigation in Kenya, or from other countries, but it is questionable whether smallholder tea producers have resources to purchase this kind of equipment without significant external investment.

Direct impacts of climate change on Fairtrade crops are likely to be less significant in the short and medium term than impacts on food crops – Butt et al. (2005) project decreases for yields of maize, groundnuts, sorghum, millet, and cowpea. Also highly significant will be major changes taking place, independently of climate change, in institutions and policies in Malian agriculture: the privatisation of the cotton parastatal and subsequent need to reshape extension and input supply institutions[18]; and the granting of leases in the main irrigated (and main rice-producing) area, which is called the Office du Niger, possibly to the detriment of small holders. Irrigation will be affected by rainfall upstream on the Niger system in the neighbouring country of Guinea (for which projections are also uncertain) and discussions (which have in the past sometimes been tense) on water use between the riparian states.

4.2.3 Dominican Republic

The Dominican Republic is the world's largest exporter of Fairtrade cocoa and Fairtrade bananas, the world's fourth largest exporter of Fairtrade fruit and vegetables, and a significant exporter of Fairtrade coffee.

The climate is humid overall: the rainy season is from May to November, during which most regions receive 100–200mm per month. Average temperatures range between 20–25 ^{O}C December–February and 25–27 ^{O}C June–November. The country rises to 3175 metres, so there are additional temperature differences based on altitude. The El Niño Southern Oscillation causes inter-year variations with El Niño events bringing warmer and drier conditions, La Niña events colder and wetter conditions, both during June–August. La Niña events are also associated with an increased frequency of hurricanes.

Mean temperatures have increased since 1960, especially June-November, as have frequency of hot days, especially June-August, and hot nights, especially September–November. Mean rainfall is decreasing, especially in June–November.

Mean annual temperatures are projected to increase by 0.3–1.2 ^{O}C by the 2030s, and 0.5–2.3 ^{O}C by the 2060s (note lower projections than for the African countries). There will be substantial increases in frequency of hot days and hot nights, up to 68% and 72% respectively by the 2060s.

Long-term projections are fairly consistently suggesting for decreased rainfall, and a decrease in heavy rainfall events. As for the Caribbean as a whole, projections are for more intense hurricanes, but with uncertainty over frequency of hurricanes, changes in storm tracks and interactions of hurricanes with other climate features. It is possible that increased summer rainfall associated with hurricanes may counteract the decreases predicted by GCMs.

Cocoa can be grown under relatively high temperatures, and the probable lesser degree of warming in the Dominican Republic, compared to African countries, gives smaller cause for concern (and there is also a possibility of adaptation through planting of shade trees), but drying may be a concern, depending on within-country differences in rainfall.

Bananas similarly will be relatively tolerant of temperature increases but again decreases in rainfall will be a cause for concern, and may need to be counteracted by increased use of small-scale irrigation. The favourability of climate to Black Sigatoka Disease is small and likely to remain so under global warming (De Jesus et al. 2008). As elsewhere, fruit and vegetable quality may be adversely affected by higher temperatures – this will have to be reviewed for specific crops and micro-climates. Coffee will be subject to strong altitude effects, so a more detailed review will have to be undertaken, both on impacts and on the advisability of planting shade trees.

Fairtrade producers, like other farmers and other citizens of the Dominican Republic, will be put at risk by the projected increased intensity of hurricanes under global warming. This applies particularly to producers of bananas with their shallow root systems and large fragile leaves.

[18] However, the Fairtrade cotton producing areas appear to be in the southwest (FTF website), outside the core cotton zone and where the presence of CMDT the former cotton parastatal was less felt.

5. Reviewing the evidence on the impacts of climate change on global trade in Fairtrade commodities

We explore here the evidence base on the potential trade impacts of projected climate change in key Fairtrade commodities, although it is important to recognise that Fairtrade growers will not only be affected by changes in Fairtrade crop yields, but also by the impacts of food crops and food security (which could lead farmer to uproot perennial and cash crops for example), increased human disease incidence, and potentially by climate induced internal migration.

There is very little literature on the impacts of climate change on the commodities traded under Fairtrade (other than rice), let alone specifically on Fairtrade trading itself.

The literature on food price movements has to take into account population, income growth, the diversion of crops and cropland to biofuel production, land acquisition by agri-business and potential switching to food crops. Nelson et al. (2009) developed a global agricultural supply and demand projection model (IMPACT) linked to a biophysical crop model of the impact of climate change on selected crops: rice, wheat, maize and soybeans. By their analysis, even without climate change, global prices for crops such as rice, wheat, maize, and soybeans will increase between 2000 and 2050. The price of rice is projected to rise by 62%, maize by 63%, soybeans by 72%, and wheat by 39%, even in a scenario with no climate change. Climate change would then lead to additional price increases, with a total of 32–37% for rice, 52–55% for maize, 94–111% for wheat, and 11–14% for soybeans. The headline figures in the model result do not include positive effects of carbon fertilization on yields. With carbon fertilization these price projections will be lower by 10%, but still represent substantial price increases.

Unfortunately, this modelling of staples tells us very little about climate trade impacts on Fairtrade. Fairtrade commodities are in general non-necessities for which demand may increase with population and with increasing incomes in developed countries, middle-income countries and among more favoured groups in less-developed countries. For example, increasing affluence in China and "westernization" of Chinese tastes may greatly increase Chinese demand for chocolate and coffee in the future.

However, this still leaves three areas of uncertainty:

- whether increased demand and thus increasing world prices in general will be translated into increasing demand for Fairtrade products and the ability to maintain Fairtrade, extend it to more producers, and extend it to new consumer markets such as the emerging economies;
- whether a concern in developed countries for 'food miles' and similar concepts may operate against trade in these commodities including Fairtrade schemes, especially where commodities are air-freighted (as seen in the continuing debate in UK on the ethics of sourcing cut flowers and horticultural products from tropical countries). With new EU legislation buyers could switch suppliers where GHG emissions are already or more easily measured, challenging Fairtrade suppliers especially small producer organisations;
- whether increased demand and (in optimistic scenarios) increased prices can counterbalance the higher costs of production, the greater risks of crop damage and crop failure (from droughts but also heavy rainfall events and tropical storms) and the major potential reductions in land suitable for certain crops (especially coffee).

6. Identifying possible adaptation strategies for Fairtrade

We earlier introduced the distinction between farm- (or management unit-) level adaptations and institutional- or policy- level adaptations. This section considers potential adaptations within each category of relevance to small-scale Fairtrade farmers. A third sub-section discusses adaptations relevant to estates and hired agricultural labour, where they are subject to Fairtrade standards.

6.1 Farm-level changes

The following discussion draws on various sources (e.g. Howden et al., 2007; Mortimore and Adams, 2001) including our own experience in agricultural development and climate change adaptation.

6.1.1 Cropping adaptations

Altering the timing and location of cropping activities is a farm management change noted by Howden et al. (2007). Many smallholders *already* spread their activities over different fields and terrains – in Peru, for example, many smallholders exploit different altitudes to plant different potato varieties to spread risk and Mexican smallholders intercrop beans, maize and squash, cultivating different maize varieties some of which are fast maturing and others that are more drought prone. Intensifying climate change, increasing hazards and longer-term trends may rely on adept use of agro-biodiversity and adaptive farming.

Modifying inputs could include use of varieties and species (where available) that have more appropriate thermal time and vernalization requirements and/or increased resistance to heat shock and drought (Howden et al, 2007). Fertilizer, irrigation and other water management can all be tweaked in terms of altering amounts and timing. In marginal areas, 'response' farming is observed, in which some producers (e.g. sorghum farmers in Yemen) practice quite sophisticated systems of response farming. For example, if rains are late or patchy, the seed is planted deeper; If mid season rains are poor then stands are thinned, and fertiliser applications are reduced. If late season rains are poor then leaf stripping is practiced.

A variety of agro-ecological technologies can be employed to improve the resilience of farming in the light of climate change. Deep cultivation by hoe or animal traction is insufficient to provide full root zone preparation for many plants. Sub-soiling can much improve the root zone volume and enable crops to grow in areas of reduced rainfall. *Protecting* crops is important as climate variability increases and climate means shift. For example, modification of the micro-climate can be achieved through the use of shade netting, poly tunnels etc. *Windbreaks* can also provide protection by reducing evapo-transpiration in semi-arid areas, and may help to reduce wind damage to sensitive crops such as bananas as extreme weather events increase.

Agroforestry will also provide important adaptations for Fairtrade commodities. *Tree shade*, for example, can be effective in reducing temperature effects on sensitive crops, and can be useful in nutrient recycling (e.g. Inga species in coffee). The reviews of climate change impacts on particular species above suggest that provision of tree shade may be a major potential adaptation for coffee, tea and cocoa[19] against rising temperatures. However, it will require forward planning across a timescale of years, thus a degree of training/capacity-building for farmers.

6.1.2 Improving the effectiveness of pest, disease and weed management practices

Climate change will affect the epidemiology of plant pests and diseases and will require different weed management practices. The extended uptake of integrated pest and pathogen management, the development of varieties and species more resistant to pests and diseases and the maintenance or improvement of quarantine capabilities and monitoring programs are all key measures outlined by Howden et al. (2007).

6.1.3 Plant breeding

A cycle of plant breeding from start to release of a new variety of an annual crop used to take around 12 years (although with gene manipulation techniques this can be reduced to 3–5 years. However, given the uncertainties of climate change projections this complicates plant breeding a great deal because of the long lead times involved. Conventional plant breeding has in the past been focused on yields and uniformity – removing some of the natural climate change adaptation capacity of crops – compared to wild plant populations. Wide crosses (between different species) will be needed to transfer drought or heat tolerance from a wild to a cultivated species should also increase the potential for relatively rapid response to temperature rise and its indirect effects on other climatic factors.

Many Fairtrade crops are perennials (tea, coffee, cocoa) and so these timescales may be longer, especially if yield assessments are conducted. In Kenya, it is currently illegal to uproot tea bushes, so even if good new planting materials are developed and made available then uptake will not be widespread unless there are policy reforms (Kleih et al., forthcoming).[20]

6.1.4 Irrigation and improved water harvesting and management

Water may become scarce in some situations for different reasons (e.g. rainfall, fast runoff induced by reduced tree cover, poor infiltration, salinity alternative uses etc). Crops such as tea are increasingly irrigated to extend the season and improve quality. The efficient use of water will be important (micro-emitters etc). Fairtrade organisations may need to look to places like Israel, California and North Australia (Queensland) for technologies that use water efficiently and effectively, and even at the use of saline water treatment in some instances (e.g. for cotton). However, the cost implications of these technology shifts could be prohibitive.

6.1.5 Soil conservation

There are a variety of agro-ecological methods which can help to conserve soils. Mulch can reduce soil temperatures (and soften soils liable to capping) and reduce evaporation for improved germination. For some crops (particularly small-seeded cereals) seed soaking prior to sowing can greatly improve germination and establishment when there is moisture shortage after planting. Improving soil organic matter improves carbon sequestration (which may be eligible for carbon-trading credits) and also buffers the soil against acidification by CO_2 rich rain, against temperature swings and against moisture deficits. Use of organic composts and manure will therefore be very important.

6.1.6 Diversification of the farming system

Fairtrade might need to further support diversification on farms or at least in communities to spread risk.

- Use of different varieties and clones (where available) within a single commodity, as they may have different properties that spread risk between seasons. In the same vein, mixed crop/livestock farming uses resources more efficiently and further spreads risk.
- New commodities/products: Fairtrade will need to continually extend its range of products standards to encourage those that are suitable for the new conditions – such as a switch from rice to shrimps in Bangladesh where seawater incursion is ruining paddies. Training and use of premiums for investment in crop diversification is also feasible. Sharing lessons through farmer-to-farmer exchange via Fairtrade networks may be important on cultivating new crops or crop varieties, or adopting new methods.

These farm-level, mainly agronomic, modifications may be particularly relevant as responses to specific climate trends. The category of hazard or climate change trend is relevant in shaping adaptation responses. We have developed a set of general climate change trends[21] against which agricultural

---

[19] Cocoa is already grown under tree shade in other countries, such as Papua New Guinea. Previously, cocoa was grown under coconut trees, but increasingly other tree crops such as Gliricidia are being used, so there is plenty of existing knowledge to learn from (T.Stathers, NRI, *pers. comm*, June, 2010).

[20] Fairtrade may be able to draw upon its cross-country coverage in terms of support of testing new varieties.

[21] This form of presentation draws on unpublished work by Tanya Stathers and colleagues at the NRI. In any given Fairtrade location it will be important to review the scientific evidence and modelling, such as it is, to establish which climate change trends are expected over different time periods (short-term, medium-term and long-term). It has not been possible within this study to provide detailed scientific projections and vulnerability impact assessments for each Fairtrade country, the relevant regions within them and each crop they produce. However, these generic trends provide some guidance as to the types of adaptation strategies which could be employed.

adaptation actions by different actors can begin to be mapped out. They include: general increase in temperature; increased average rainfall; decreased average rainfall; increased frequency/severity of drought; increased frequency/severity of heavy rainfall events; more frequent occurrence of high winds. The climate trends, are **not** climate scenarios. The general warming trend will be present in any realistic scenario and the others are not all mutually exclusive.

The table below sets out which modifications may be of especial importance in situations where a particular trend is occurring. The table also classifies these adaptations according to the degree and sort of support farmers will need to adopt them.

Table 8 Climate trends, key actors, support required and agronomic adaptations

General climate trends	Farmer roles and types of support required
Farmer roles and type of support needed	**Potential adaptations** The options open to any given farmer will depend on their own internal resources; their working context/environment (social, economic, institutional, biophysical etc) and this will change over time. This will determine whether adaptations are for example: • implementable by farmers without external agencies (eg changing planting dte based on experience of previous years) • Implementable by farmers but requires new knowledge eg new ways of water harvesting • Implementable by farmers with access to new forms of finance eg purchasing irrigation equipment • Requiring institutional change or multi-stakeholder collaboration eg access arrangements for irrigation facilities. External agencies may be in the public or private sector
Widely applicable	Adopting different crop varieties (subject to availability) Altering timing of crop activities – including “response farming” Altering irrigation management (where systems already exist) Adopting different crop species (annual crops) Improving integration between farm activities (e.g. crops and livestock) Improving the effectiveness of pest and disease management Adopting different crop species (perennial crops) Crop diversification Plant breeding
General increase in temperature	Planting shade trees Use of mulch Shade netting
Increased average rainfall	Improving soil organic matter (e.g. through improved drainage, terracing, other soil conservation measures
Decreased average rainfall	Water harvesting Windbreaks (to reduce evapo-transpiration Deep cultivation (sub-soiling) Establishing or upgrading irrigation systems
Increased frequency/severity of drought	Water harvesting Establishing or upgrading irrigation systems Crop insurance
Increased frequency/severity of heavy rainfall events	Water harvesting/soil conservation (as above) Establishing or upgrading irrigation systems
More frequent occurrence of high winds	Windbreaks

Adaptations to specific Fairtrade crops are set out in table 9 below. Different situations and contexts will require different responses, but lessons and 'best-bet' technologies can be shared and piloted between groups.

The next section sets out broader policy and institutional changes (including farm level changes) which could build the adaptive capacity and resilience of Fairtrade farmers.

6.2 Policy and institutional changes

To change the decision-environment a range of policy-based adaptations can be identified which if implemented might lead to more systemic changes in resource allocation (e.g. through alternative land use and livelihood options). Examples include infrastructure development, capacity building amongst broader user communities and institutions and modifications in management level activities through mainstreaming (Howden et al., 2007).

Within Fairtrade it is important that suppliers are convinced of the reality of climate change and helped to understand if and how it might affect their enterprise. Fairtrade suppliers may need increased access to technical and social innovations. At a broader level there may be the need for more structural transitions (e.g. land use and resource entitlements and changes in agriculture and trade policy) if adaptation to climate in the longer term is to be achieved. Here Fairtrade suppliers can play a role by engaging in national level adaptation processes (e.g. in the NAPAs) and beyond in international climate policy. The producer networks represent a significant opportunity for advocacy activities in all aspects of rural agricultural development and trade policy, but in particular have a role to play in engaging with the climate agenda.

Some of the policy-based and institutional innovations that could be of particular relevance to Fairtrade are discussed below.

6.2.1 Build up climate knowledge of producer groups

It is important to understand what climate knowledge/information farmers have first of all, as well as other key actors in the agricultural innovation system. Producer organisations and estates may not have good access to scientific climate information, particularly in forms that is accessible. More also needs to be known about the trends farmers are experiencing, observing and interpreting in relation to changes in climate variability and extreme events. Fairtrade organisations could provide this support but could also link up via partnerships with other organisations to do so. It is important that the materials are accessible for farmers to understand and that attention is paid to the ways in which this information is understood by users and interpreted. This information aspect of climate change will be a critical role for Fairtrade organisations. Farmers need support to look beyond the next couple of years and to participate in local processes of innovation and learning. Fairtrade can play a role here in sharing lessons, ideas and technologies across its various networks and linkages.

Table 9 Fairtrade crops and some examples of possible technological adaptations

Fairtrade crop	Possible technological adaptations
Rice	Improving water storage and irrigation facilities Development of drought tolerant varieties and diversification into suitable non-rice crops Plant breeders to develop tolerance to salinity
Cotton	Changes to crop management practices to conserve water and reduce soil degradation. Moving from surface furrow irrigation to sprinkler or drop irrigation greatly improves the efficiency of water use. Greater use of minimum and zero tillage practices.
Vegetables	Impossible to generalise given the wide variety of crops and production systems.
Coffee	More use of shade trees Mulching coffee plants with the prunings from shade trees Use of drought-resistant varieties Supplementary irrigation.
Cocoa	More use of shade trees
Tea	Drip irrigation More use of shade trees
Bananas	Improving water use efficiency (e.g. by using drip irrigation systems) Improving drainage and soil conservation on slopes Black Sigatoka control strategies as key components of banana crop management systems
Sugar cane	Sprinkler irrigation

A study of shea kernel collectors and shea butter producers indicates that they are observing changes in climate variability (Masters, 2009). Whilst climate variability changes should not be conflated with climate change, and other reasons for drops in yields should be considered, this study does providing interesting information about current adaptive strategies which may form entry points for working on climate change – although in the longer-term climate change may require different kinds of strategies.

6.2.2 Encourage all producer groups and enterprises to integrate climate considerations in their planning and impact assessment

Changes should be made to FLO standards to note indicate the importance that producer groups and enterprises integrate climate change considerations into their planning and in their evaluation exercises, drawing upon the new information and support provided by FLO or partners.

6.2.3 Support participatory adaptation processes at community level

Support producer groups and estates to conduct adaptation planning through vulnerability and resilience assessment, identification of options, implementation and learning in a participatory process that is integrated with on-going organisational planning processes as far as possible. See Table 10.

Box 3 Observation of climate variability amongst shea collectors and processors in West Africa

Shea collectors and processors in Ghana and Burkina Faso are observing clear trends in increasing climate variability (reduced and more erratic rainfall, increasing frequency of extreme weather events such as successive flooding and parching) with reductions in productivity due to soil degradation and loss of vegetative cover. The income from shea kernel and shea butter is of increasing importance to rural livelihoods, but yields have been decreasing. Some farmers are responding by implementing soil and water conservation measures, tree planting, implementing rotation and fallow, composing of manures and contouring, water harvesting, maintaining on-farm diversity, and on a very limited scale small-scale irrigation. Some households are reducing household food consumption or sending children to work in the towns. Provision of technical support for improving product quality control, adding value, and product certification are recommendations of the study. A regional platform for technical exchange on key issues of adaptation could bring together disparate communities and households. Production of an inventory of locally-adapted crops and crop cultivars including both traditional and 'improved' varieties, particularly short-maturing grains and pulses as well as horticultural and tree crops of a diversified parkland agroforestry

Source: Masters, E. (2009)

Table 10 Key Steps for participatory adaptation process

Stage 1: Conduct initial assessment with local community	Conduct desk-based review of climate knowledge to gather and assess clarity of climate knowledge amongst secondary stakeholders (precision, availability, uncertainty etc) Share climate information (e.g. from national vulnerability assessments) with local community and producer group to raise awareness Learn from group members about their observations and interpretations of climate variability and change Explore 'starting point' vulnerability with producer group and wider community Assess adaptive capacity (decision-making, patterns of resource entitlement) & livelihood resilience (frequency of disturbances, climate sensitivity, risk management, ecosystem health etc).
Stage 2: Assess vulnerability to and potential impacts of specific climate hazards and trends	Identify (nature of) top climate risks facing the local group and how it might affect different livelihoods and resources Consider how different groups will be affected (gender, age, caste, class, ethnicity etc)
Stage 3: Identify options for building adaptive capacity and implementation	Identify on-going adaptive strategies to existing climate variability and emerging trends Identify individual innovators ('positive deviants') for potential support Explore different scenarios given new climate change awareness and consider desirable pathways Identify and agree adaptation actions (technical and social innovation at farm level, policy and broader institutional changes and associated advocacy strategies etc) Identify potential sources of funding that could be tapped into Develop communication/action plan (separate actions that individual farmers can take, the producer organisation can undertake, support required from external bodies) Implementation and review process

Source: Authors' own work

6.2.4 Provision of financial support for transition

Many of the farm-level changes outlined above will require transitional funding to compensate for lost income and/or to secure a livelihood while a key asset is unproductive – for example income while a new planting of a different coffee variety comes to yield. This would be similar to the governmental funding given to farmers in the UK for transition to organic farming. Transition would need to be based on realistic feasibility studies and market studies/linkages.

6.2.5 Improve on-going access to weather information

Providing farmers with better weather and seasonal forecasting information and early warning systems (based on observation and local knowledge fed back by mobile phone from remote locations) may improve the chances of crop success through timely planting and other field activities. There is significant on-going work to explore how best to link farmers to seasonal forecasts and to understand barriers to understanding and acting upon probabilities. Information on longer-term climate change trends should also be made available in accessible and appropriate formats to poor communities as an initial step in awareness-raising in participatory adaptation planning processes and in concert with learning from communities of their own observations and interpretations of climate change. There are many toolkits emerging on facilitating adaptation planning which could be drawn upon and adapted by Fairtrade bodies for use with partner organisations.

6.2.6 Contingency planning and crop insurance

It is assumed that risk of crop failure will rise in some situations. One way of adapting to this is crop insurance. Crop insurance in developing countries has long been regarded as unfeasible except for small numbers of commercial farmers, because of problems of high transaction costs (including avoiding corruption and complicity by those verifying crop losses), adverse selection (farmers may only insure those fields or crops at the highest risk, leading to higher costs for an insurance company) and moral hazard (farmers may put less effort into managing crops or fields that are insured).

In recent years though there has been an increase of interest in *index-based insurance*, where payouts are made not against some level of damage to the insured farmer's crops, but against some objective and specified meteorological event in the area (e.g. rainfall at the nearest rainfall station falling below 50% of the long-term average for the months of the growing season). As well as objectivity and fewer opportunities for subornment, index-based insurance has the advantage that it can be sold in very small denominations, i.e. a farmer can pay a small or a large premium depending on his/her needs, and will receive the same ratio of payout to premium if the specified event happens. However, it does depend on a dense network of weather stations, and the ability to define a weather event that is a reasonable proxy for crop failure causing distress among farmers. Index-based insurance may also become less feasible if the climate parameters that define events triggering payouts are changing – but similar objections hold for traditional insurance of crops. To operate as genuine insurance schemes, rather than relief in the event of disaster, insurance would have to operate at large scale, across different climate zones, and with professional design and actuarial expertise.

In principle, Fairtrade intermediaries could facilitate provision of crop insurance on either traditional or index-based lines, but this would depend on ongoing schemes or the capacity to establish them at scale already existing. Fairtrade organisations could include crop insurance in their standards, although this would require technical support and new linkages on the part of FLO.

In some instances the Fairtrade Premium has been used to set up a contingency fund against natural hazards. In Belize, the premium has partly been used to create a contingency fund to cover emergency food relief packages for Belize Sugar Cane Farmers' Association members who were affected by severe flooding. Contingency funding can help to offset vulnerability to climatic risks. At the local level and following awareness-raising on climate change and planning processes for responding to climate change challenges, a farmer organisation might decide to allocate funds for contingencies where they are likely to be affected by drought and floods, but such a use of funds would probably compete with other uses of a more immediate nature unless premium amounts are relatively high.

It may also be preferable to help link up producer organisations to social protection mechanisms of government where these exist or to increase their lobbying through Fairtrade networks for the provision of such initiatives (e.g. asset and cash transfers, seed fairs etc) in times of crop failure or crisis. Improved access to rural agriculture finance (e.g. through micro-savings and credit schemes) would also help to tackle the underlying drivers of vulnerability for many Fairtrade farmers.

6.2.7 Agricultural learning, extension and innovation

Agricultural adaptation often starts from existing climate variability adaptive strategies and there is a great deal of existing agro-ecological methods that can be implemented with technical training and capacity building which would increase farmer and ecosystem resilience. There is also increasing amounts of agricultural adaptation action research being undertaken and new linkages could be made to draw upon relevant findings for Fairtrade producers and estates.

Access to *adaptive* extension (i.e. extension that takes into account climate change trends and builds farmer capacity to observe and experiment) advice should be supported by Fairtrade bodies and/or governmental extension bodies where this is available. Specific agronomic adaptations have been outlined in the previous section. It is important that extension is gender sensitive (see Martin and Nelson, 2008 on key issues for gender in agricultural extension) as a general rule, but given that climate change is likely to affect women disproportionately this will become more important than ever.

Specific changes could be made to the producer standards to strengthen environmental requirements, but only once the social implications have been explored with farmers, including labour burden and technical support requirements etc. Fairtrade banana growers in the Windward Islands complained about the restrictions on the use of a specific herbicide included in the Fairtrade standards, which increased the demands on their labour and disproportionately affected older farmers who had to hire others to complete the work (Moberg, 2005).

Capacity building support is likely to be crucial in developing and sharing existing and new technologies and practices for adapting to climate variability and change. Learning alliances or platforms can be developed to facilitate this learning, involving not just community level and local actors, but stakeholders from across the innovation system (e.g. farmers and labourers, local farmers who are innovators – also known as 'positive deviants', large traders and intermediaries, suppliers, researchers, extension workers, seed suppliers, fertilizer suppliers, government representatives, credit providers, etc)[22].

6.2.8 Improving ecosystem stewardship

Strengthening ecosystem stewardship will underpin livelihoods and wellbeing and a healthy environment acts as a buffer to climate shocks and stresses – which are set to intensify. A degraded environment is more likely to leave farmers more vulnerable to climate hazards. Creation of linkages with conservation agencies may be desirable, to increase training on the value of ecosystem services, and to implement environmental conservation and more environmentally friendly farming.

Agroforestry initiatives will be important in climate change adaptation, potentially providing mitigation and adaptation benefits. Where funding can be leveraged this could be important to overcome some of the barriers to smallholders investing in tree planting. In Kenya the smallholder producer organisations in tea has approximately 1000–1,500 hectares under tea and so for both these and the estates agroforestry or tree planting will be mitigation options, especially where this might tie in as shade cropping adaptation longer term (T.Stathers, NRI, *pers.*comm. 2010).

Payments for ecosystem services are likely to provide a significant incentive for improved ecosystem stewardship (see next section), where these funds can be accessed. Advocacy work may also be needed to challenge governance arrangements where power inequalities are strong and more structural transformations are needed to secure healthy ecosystems and sustainable livelihoods for rural populations. Moreover, the insights of resilience thinking should be drawn upon in thinking about landscape and social change processes (see Walker and Salt, 2006).

6.2.9 Payments for ecosystem services and climate finance

Payments for ecosystem services (e.g. carbon sequestration) represent an obvious opportunity for Fairtrade farmers and FLO to build upon the organisational strengthening they can achieve to tap into funding, which could potentially provide much needed investment in environmental protection. There are still many questions regarding the effectiveness and impact of payments for ecosystem services, and the broader questions of equity in attracting additional funding to Fairtrade producers rather than other disadvantaged farmers[23], but the advantage of FLO Fairtrade is the organisational structure in place. Fairtrade provides support for capacity building, organisational formation/strengthening and auditing which carbon financing schemes (mitigation and adaptation) may be interested in.

Climate finance represents an important opportunity for Fairtrade producer groups and enterprises, although there have been bottlenecks in getting funding to local communities for mitigation activities in Sub-Saharan Africa especially. In situations where there are large numbers of smallholders in an organisation they too will be faced with questions regarding their carbon footprint[24]. Fairtrade organisations should thus find ways either to support Fairtrade suppliers, especially smallholders, to be able to measure their GHGs, with appropriate methodologies, leveraging in investment from Fairtrade buyers. Buyers would benefit in terms of enhanced reputation but also to secure future supplies of Fairtrade products.

Voluntary carbon market standards, such as the Gold Standard, have newer micro-projects which tackle energy poverty and which deliver adaptation as well as mitigation benefits. They still require measurement of emissions, however, and tree planting or protection has resource implications for smallholders. Support is needed if smallholder groups in particular are to be able to measure their emissions and apply for such funding. Linking between communities can also help to increase the scale of mitigation activities – Kenyan tea producers are already conducting indigenous tree planting, finding alternative power sources, looking at waste management, soil mulching and terracing etc (T.Stathers, *pers.comm.* 2010).

Public adaptation funding represents another opportunity for Fairtrade and will not require complex emissions measurements, but they should be targeted at particularly vulnerable communities, and so producer groups would need to show they are vulnerable to climate risks.

---

[22] A Climate Change Adaptation for Africa (CCAA) project is developing this innovative approach in Tanzania and Malawi. The project focusing on agricultural adaptation through vertical and horizontal learning alliances from local to national level are bringing together agricultural innovation system actors for collective action and commitment. The project is led by the Institute of Resource Assessment, Tanzania and Chancellor College, Malawi in collaboration with the Natural Resources Institute, University of Greenwich, UK. See the project website **www.ccaa-agrictama.org** for more details.

[23] The 'honeypot' effect was noted some years ago (Nelson, et al, 2001) in relation to Fairtrade, with farmer groups linked into Fairtrade often attracting donor funding.

[24] Beyond carbon footprinting, it is likely that ecological footprinting and life cycle analysis will be required, because of issues such as water, especially in certain crops such as cut flowers.

Private sector adaptation funding has been limited to date but will increase as companies seek to be thought leaders or respond to public pressure to tackle the human cost of greenhouse gas emissions. Fairtrade retailers and traders could be approached to implement a climate responsibility approach which goes beyond or replaces offsetting. As well as reducing their emissions such companies should be encouraged to work with Fairtrade suppliers a) to secure their supply of products by investing, b) to maximise the impact of Fairtrade, c) to secure reputational benefits. This kind of value chain partnership should complement the on-going Fairtrade work with companies on mitigation.

6.2.10 Changing the content of standards

Encouraging more environmentally friendly farming is already part of Fairtrade standards, but more could be done to strengthen areas of these standards which are weak compared to other environmentally oriented labels (e.g. FSC, Rainforest Alliance). More environmentally friendly farming in many cases helps to spread risks and increase agroecosystem resilience. Farmers may then be further encouraged to reduce and reverse environmental degradation which negatively affects water supply, leads to increases in wind erosion, loss of biodiversity and common-property resources - the latter being important resources for the livelihoods of the poorest and for women. However, we recognise the difficulties which many farmers already face to meet some environmental requirements because of the labour and costs involved. There are already moves afoot within Fairtrade to lighten the standards to reduce the burden on farmers of auditing. It may be as important that Fairtrade organisations provide capacity building support for environmentally friendly farming (directly or via partnerships).

6.2.11 Livelihood Diversification and Migration

Beyond diversification in cropping, mixed crop and livestock farming also merits attention in adaptation because as a system it tends to use resources more efficiently and further spreads risk. Beyond agriculture livelihood diversification is likely to be a key element of adaptation to climate variability and change and in fact non-farm livelihood activities already represent an increasingly important element of rural livelihoods in many countries[25]. Non-farm livelihood activities are important for generating and diversifying sources of income for rural dwellers and economies.

Smallholder economic resilience (the ability to cope with and recover from economic shocks and stresses) may depend upon diversified livelihood activities and income sources. Market volatility is a key issue for smallholders. Assessments of the impact of Fairtrade which focus only on income fail to sufficiently recognise the safety net or buffer that Fairtrade provides through the Fairtrade pricing mechanism, encouragement of longer-term trading partnerships, sometimes diversifying buyers etc. In Latin America where coffee farmers having suffered from a world market coffee price crash Fairtrade farmers value highly the stability and security provided by Fairtrade. In situations where the Fairtrade price is equivalent or below world market prices new entrants may not value this safety net function to the same degree.

There is mixed evidence about Fairtrade impacts upon smallholder and worker households in terms of whether it leads to greater specialisation or diversification of incomes and livelihood activities. A recent comprehensive review of the impact evidence base (Nelson and Pound, 2010) found that ‘the guaranteed price, long-term contracts and access to credit has also given farmers in some instances the security to diversify their source of income thereby further reducing vulnerability. Seven studies cite examples including improvement of food security through organic gardening or small livestock production[26]’ (Nelson and Pound, 2010, p2). Some Kenyan tea estates are already diversifying their activities into other crops, which may assist the estates to spread risk. In some situations positive Fairtrade outcomes (e.g. good and stable prices) have led to activity specialisation, thus reducing the degree of income diversification (Ruben et al., 2008 cited by Nelson and Pound, 2010). However, information on whether Fairtrade workers and their households are able to diversify their livelihood activities and sources of income is negligible.

The focus on export cropping in Fairtrade may encourage farmers to invest more in specific cash crops, away from food cropping, with implications for household food security and the gender division of labour. Clearly, a balance needs to be struck between diversification and risk spreading with asset building. It is thus important that Fairtrade impact assessments consider the livelihood activities of all household members and the (potentially changing) level of resilience of the household to shocks and stresses.

If climate change induces migration it is much more likely to lead to greater in-country migration (and rural to rural, as well as rural to smaller towns, and rural to urban), although natural population increase will be a key factor in urbanization. Moreover, the decision to migrate is a complex one, involving economic and political factors as much as environmental ones. However, in many regions of the world seasonal, temporary and circular migration and mobility is already increasing, in response to chronic environmental degradation and other stressors (e.g. land fragmentation, HIV/AIDs, regionalising and globalising markets, etc), but this type of non-permanent migration is under-recognised by policy-makers and tends to be less visible in national statistics.

[25] The 1994 Ministry of Agriculture survey in China, for example, shows that non-farm incomes and internal transfers from rural migrants to urban centres were about to overtake earnings from agriculture in rural household budgets (cited by Tacoli, 2009).

[26] Other studies also reviewed in Nelson and Pound (2010) also showed different levels of diversification and intensification: ‘In El Salvador and Mexico, (Murray et al., 2003) found that co-operative members were able to diversify into handicraft production, establishment of community stores, development of bakeries and improved production of basic grains. One study of Costa Rican coffee found activity specialisation was increased by participation in Fairtrade, leading to less income diversification, especially where co-operatives were able to sell a major share of their production to Fairtrade outlets’ (Nelson and Pound, 2010, p2). In Ghana Mayoux (2004, reporting Ronchi, 2002b) felt that it was likely that the Kuapa Kokoo credit programmes had increased diversification and hence incomes, particularly for women, although this credit facility has suffered some setbacks of late (Nelson, Bugri and Martin, forthcoming).

Intensifying labour migration is a critical response in rain-fed agricultural areas to diverse pressures (which could include climate change in the future) as a means to diversify income sources (Raleigh and Jordan, 2009). Farming in another location, engaging in non-farm activities when labour is less needed on farms and seeking employment in urban areas represent three common types of labour migration (Tacoli, 2009). Remittances and non-farm incomes help to finance innovation and farming intensification in Sub-Saharan Africa and play an important part in rural safety nets (Tacoli, 2009). Support for small towns and large village development may be important in linking smallholder farmers to wider markets, but also in providing them with services and non-farm employment opportunities – regardless of climate change, but also increasingly so where climate change significant stresses rural populations.

6.2.12 Estate agriculture and hired labour

FLO has moved into hired labour situations in recent years enabling estate agriculture in cash crops such as tea, coffee and bananas to be certified. The potential climate change impacts for each of these crops have been outlined above in Section 3. Hired workers on large estates are 'intended beneficiaries' of Fairtrade alongside smallholders, but they tend to have less power to participate in agricultural adaptation directly. Estate management is more likely to gain access to climate information to understand the impacts of climate change for productivity, profitability, and sustainability and to have the resources and capacity to explore adaptation options. However, farm workers may also be keen to engage with adaptation learning, as production practices that improve productivity and sustainability improves their job security and may increase their earnings[27]. Conversely, if climate change has negative impacts on estate production and profitability this could undermine worker job security. There is an opportunity for Fairtrade organisations to engage with joint bodies and worker representatives as well as estates management in exploring adaptation options. There may be opportunities to educate Joint Bodies and worker representatives about climate change science and to explore adaptation options especially where these also meet development objectives or increase productivity etc. There may also be opportunities to seek additional climate financing to invest in adaptation.

Buyers and actors along the value chain should also be brought into the process to fund and implement adaptation solutions, because each actor in the value chain and agricultural innovation system has a role play. Estates may have greater capacity to independently explore climate change finance opportunities for emissions reductions through changes in farming techniques and/or adaptations compared to smallholder groups. Smallholders may also benefit from estates which trial new methods, varieties, crops and approaches, where they can take up successes at significantly less risk.

Reducing emissions is of importance to plantation agriculture. Carbon labelling looks increasingly likely to draw estates into the complex debate on food and fair miles – potentially affecting job security if consumers and buyers begin to switch suppliers where greenhouse gas emissions (GHGs) are measured and lower. Fairtrade suppliers may have little choice (as new EU legislation comes into being) to retain existing EU market access but to begin to measure their GHG emissions. This is clearly a complex, costly and time-consuming task with a lack of consensus on which methodologies should be used. While smallholders will be specially disadvantaged, there will also be problems for estates. This is a risk that smallholders could, therefore, be at a disadvantage.

[27] An on-going DFID impact assessment study has found that Kenyan tea estate workers are supporting the initiatives of estate management to improve production practices and sustainability of tea cultivation for exactly this reason. Many of the tea estates included in the study are already diversifying into other crops (e.g. essential oils, flowers etc). Some workers are now using their increased free time (as a result of the overtime limits imposed by Fairtrade certification) to learn and start to practice new livelihood skills (Kleih et al, forthcoming).

7. Conclusions

Our study shows that climate change poses a great many challenges for Fairtrade, but also opportunities. It is important to recognize that there may be limits to what Fairtrade organisations and producer groups can do alone, particularly where sales on Fairtrade terms are still small and that quite often the expectations placed upon Fairtrade can large. The measures outlined above are broad in character, because of the uncertainties involved in climate change projections and the importance in agriculture of adaptation based on local, multi-stakeholder processes of innovation. However, Fairtrade sales growth over recent years is impressive. On one level Fairtrade needs to continue to grow its markets to ensure larger premiums which farmers and workers may be able to partially invest in adaptation.

Fairtrade can also build upon its strengths as a movement with global networks, with advocacy potential in climate policy arenas and as a system which builds organisational capacity and acts as a vehicle for finance to farmers and workers. New partnerships may also be needed for Fairtrade to increase its' impact and to support farmer and worker adaptation.

Fairtrade should seek to build the adaptive capacity and resilience of farmers and workers to enable them to prepare for and respond to climate variability and change. Figure 2 shows the different dimensions of adaptive capacity and resilience across the Fairtrade system and the following Table 11 sets out measures relevant to each dimension – although many of these are overlapping or inter-related of course.

Figure 2 Building adaptive capacity and resilience in the Fairtrade system

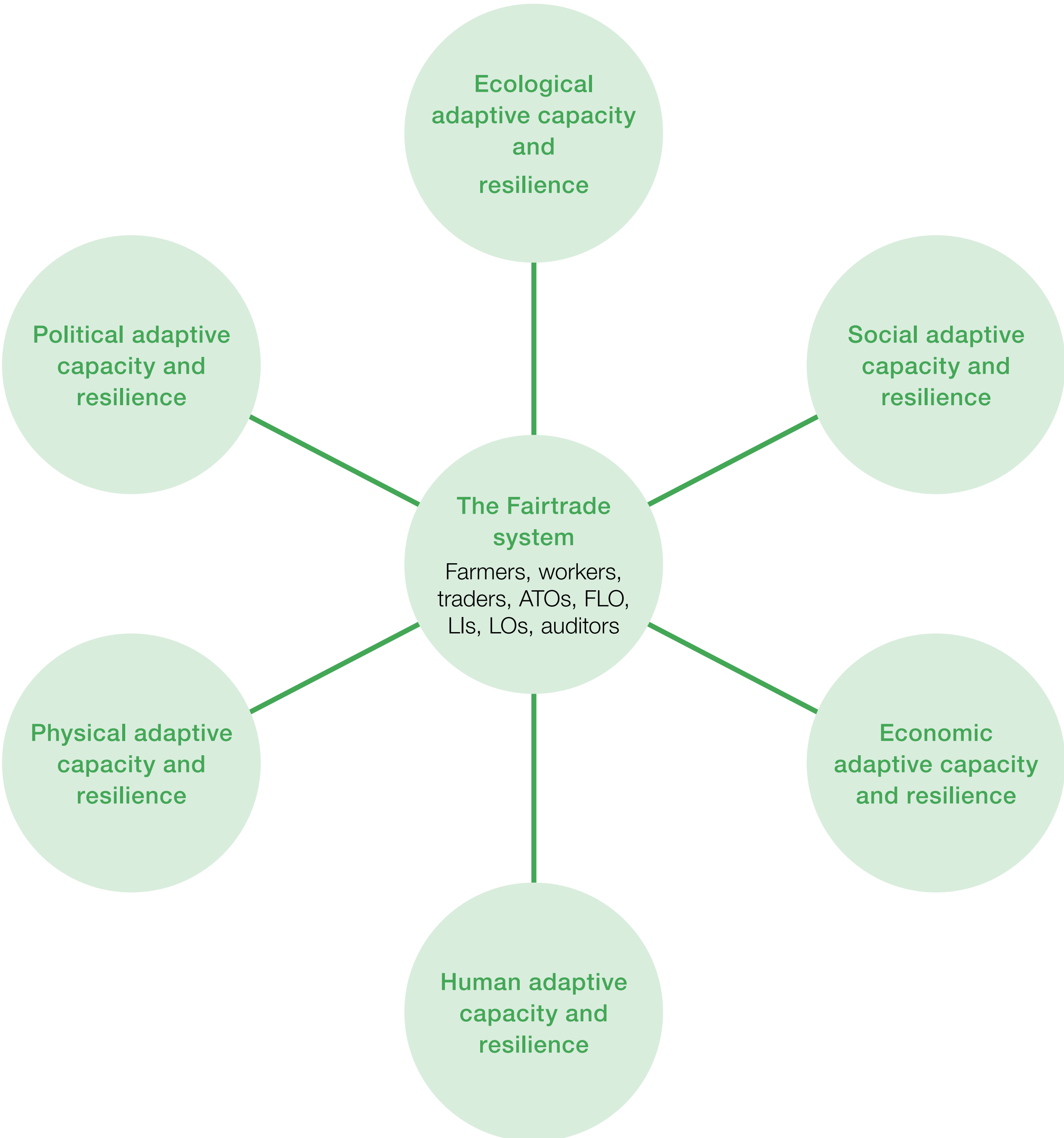


Table 11 Different dimensions of adaptive capacity and resilience in Fairtrade: some practical suggestions

Building human adaptive capacity and resilience in Fairtrade

- Continuation of and increased premiums for community development (health, education, environmental projects) as well as farm production. Health impacts of climate change (e.g. spread of diseases such as malaria in tea growing uplands in Kenya) merit consideration.
- Technical support to enable climate-proofing of infrastructure funded through the premium.
- Encourage education on disaster risk reduction and climate change in schools and farmer/worker organisations in particularly at risk locations, ensuring participation from women, children and the elderly.
- Educate consumers about climate change and development
- Draw on adaptive DRR experience and materials to support disaster risk reduction amongst 'at risk' communities

Building ecological adaptive capacity and resilience in Fairtrade

- Maintain or increase access to key natural resources such as reliable water sources, and productive land and improve natural resources management (e.g. ensure that wild resource use such as shea and brazil nuts is monitored as a first step in ensuring resource extraction levels are sustainable)
- Support for agro-ecological, climate-friendly farming methods which maximise agrobiodiversity and spread risk.
- Support learning and exchanges between Fairtrade farmers and communities on adaptive strategies.
- Seek funding to support the transition to more climate friendly farming methods and ecosystem stewardship
- Identify technologies with mitigation and adaptation synergies (e.g. system of rice intensification, community-based bioenerg, agroforestry schemes).
- Engage with the 'green consumption' issue more generally as it relates to Fairtrade, regarding reduced consumption versus high levels of green or ethical consumption.

Building economic adaptive capacity and resilience

- Increase income, provide income safety net and increase diversity of income sources. Growing markets, increasing premiums, improving quality, providing additional access to credit and saving mechanisms and micro insurance may all help to buffer poorer households against shocks and stresses.
- Consider how the Fairtrade price might reflect changes in costs of production posed by climate change factors but consider if this creates perverse incentives for farmers to stay in crops which may ultimately become inappropriate for that location
- Gather good data to better match supply and demand
- Monitor how climate change and other stressors affect markets and trade in Fairtrade commodities and the economic impacts for poorer households
- Understand better the use of premiums through impact assessment work and find ways to increase the effectiveness of its use and ensuring that premium committees and joint bodies have increased climate change awareness to bring to premium decision-making
- Ensure impact assessments consider how Fairtrade may be leading to diversification of income sources or vice versa as well as income and asset building. Also consider food crop versus cash crop balance.
- Support livelihood diversification (e.g. mixed cropping, mixed farming, off-farm activities)
- Assess the costs and benefits of different livelihood and agricultural adaptation options (including gender and social disaggregation)
- Seek opportunities for adding value and upgrading of roles in the value chain
- Review experiences on climate based index insurance to scope the feasibility for Fairtrade organisations and groups
- Explore potential for collaboration with environmental standards and labels (e.g. in joint auditing, in lesson sharing and extension, review of their new climate provisions or responses such as the SAN climate friendly module, etc).
- Support producer and worker advocacy on issues of structural transformation and policy reform (e.g. land rights, trade policy) which influence and constrain the impact of Fairtrade
- Innovate through value chain partnerships with traders to obtain investment in migration but also in adaptation. Establishing adaptation partnerships with large retailers, for example, would be a positive innovation. Help retain or secure market access of estates and producer groups by helping them to measure their footprints (e.g. by linking them to existing on-line, free tools for measuring and tackling environmental footprints (e.g. via the Carbon Trust) and links to those who can provide technical support.

Building social adaptive capacity and resilience

- Build on Fairtrade's strengths of supporting the democratic organisation of workers and producers, as this can provide a basis for collective action in adaptation.
- Understand better how rural households draw upon formal and informal social resources and networks for their livelihoods especially in hard times, with climate change likely to bring added pressures
- Challenging inequality may involve challenging less progressive networks and factions
- Explore how to link up particularly vulnerable Fairtrade producers with social protection measures (government and other development agency) where appropriate
- Continue to strengthen Fairtrade producer group networks building their voice, climate knowledge and encouraging their engagement in and advocacy around climate adaptation processes

Table 11 (continued)

Building social adaptive capacity and resilience (continued)

- Support farmer innovators' network and exchanges (potentially using participatory video);
- Increase support for *adaptive* agricultural extension including climate farmer field schools
- Create new linkages with on-going action research in adaptation with universities, national agricultural research systems, and adaptation programmes
- Seek donor funding for action research with Fairtrade groups
- Support access of Fairtrade groups to weather, seasonal forecasting and early warning systems, with attention to user uptake and own knowledge;
- Employ community radio, participatory video, animation for extension and advocacy on climate change;
- Explore the use of mobile phone technology for climate change information exchange, financial exchanges, monitoring bio-indicators;
- Consider how resilient specific Fairtrade organisations are and Fairtrade as a system (e.g. following resilience indicators of diversity, connectivity, self-organisation, learning etc).
- Integrate climate change into organisational plans and also in impact assessment processes
- Encourage and educate consumers on how to reduce their emissions because of the human cost of climate change
- Use of new social networking media and funding partnerships between consumers and farmer groups to fund and discuss adaptation
- Consider further changes to standards and auditing procedures to reduce the burden on producers and to reflect local specifics.

Physical adaptive capacity and resilience

- Continue to improve community infrastructure (shelter, water supply etc) through premiums
- Ensure climate-proofing of investments – i.e. modify existing designs and locations. Consider where more transformational approaches might be required to institutional arrangements or priorities (e.g. increasing need for irrigation, or community seed and grain storage facilities)
- Build the climate change knowledge of farmer and worker premium committees and groups to inform decision-making.

Political adaptive capacity and resilience

- Support farmer and worker direct engagement in climate change adaptation and policy arenas across scales, including the international level
- Enable farmer and worker advocacy and voice in national policy debates (e.g. on agriculture, trade etc) and their ability to lobby for increased access to key livelihood resources and investment
- Work with the producer networks to build their ability to represent Fairtrade farmers and workers
- Improve the participation and voice of women and other disadvantaged groups in household, community and national decision-making, in FLO and the producer networks particularly in relation to climate change adaptation
- Use participatory video and learning platforms to exchange ideas and build confidence.

Another way of presenting recommendations for Fairtrade is under the main avenues of impact identified by FLO (Eberhart and Smith, 2008): producer standards, the trader standards, capacity and networking. To the latter we have added policy, advocacy, governance and research. The preceding sections have outlined a great many social and technical innovations and broader policy changes and interventions that will assist in adaptation to climate change. We summarise some of these in Table 12 against the major avenues of impact.

Table 12 Fairtrade 'avenues of impact' for promoting climate change adaptation

Possible changes
Producer standards • Producer group and estate management/Joint Bodies could consider climate change in development plans • Strengthening of requirements for environmentally friendly and climate resilient farming • Encourage groups to consider use of Fairtrade returns and climate finance investment for contingencies and LH diversification where appropriate
Trader standards • Grow markets to increase sales on FT terms and producer incomes/assets • Request traders to demonstrate the steps they are taking to reduce their emissions • Seek mitigation and adaptation partnerships with value chain buyers and actors to lever investment for smallholders and workers to measure their emissions and to undertake adaptations. • Increase requirements for longer-term trading relationships which enable producers to respond to longer-term adaptation needs as well as short-term priorities • Explore the potential for linking up to climate based index insurance • Consider how Fairtrade pricing should change if climate change affects the costs of production • Develop partnerships with value chain and innovation system actors to access investment, changes in relationships and learning processes to enable adaptation. Create 'Adaptation Partnerships' with climate change thought leaders (e.g. the big retailers) to support adaptation amongst farmers and workers • Explore potential synergies with other environmental standards
Capacity building • Raise awareness on climate change amongst farmer organisations, estates and worker groups • Support the sharing of accessible and clear climate information and improve access of farmers to climate information • Capacity building support for participatory adaptation planning and action • Technical support for agronomic adaptation and for social and financial innovations • Provide support for producer organisations and estates to tap into climate finance • Create new partnerships (e.g. with the meteorological services, with local government, with input suppliers, with other agricultural adaptation projects and programmes)
Networking, policy, advocacy, governance, research • Increase the voice of Fairtrade producers and workers in local and national adaptation and other relevant policy making (e.g. land reform, participation in adaptation planning processes). • Support representation from Fairtrade producers and workers in international climate policy arenas (e.g. the COP) • Integrate analysis of relative vulnerability/resilience into impact assessment • Educate Fairtrade consumers about the damage caused by their emissions and the importance of funding adaptation. • Assess the feasibility of creating direct linkages between consumers wishing to fund adaptation because of their unavoidable emissions and specific Fairtrade groups adapting to climate change.

Climate change is a dynamic field which has implications for development which are often far-reaching. Thus whilst climate change intensifies already significant development challenges and creates huge uncertainties, there are also opportunities for the Fairtrade movement to work to its strengths to support adaptation and to consider the strategic changes that will be required.

References

Anderson, S., Morton, J. and Toulmin, C. (2009). "Climate change for agrarian societies in drylands: implications and future pathways", in R. Mearns and A. Norton (eds.), *Social Dimensions of Climate Change: Equity and Vulnerability in a Warming World*. Washington, DC: The World Bank.

Anim-Kwapong, G.J. (2003) Potential of some Neotropical *Albizia* species as shade trees when replanting cacao in Ghana. *Agroforestry Systems* **58**: 185–193.

Anim-Kwapong, G.J.and Frimpong, E.B. (2004) Vulnerability of agriculture to climate change- impact of climate change on cocoa production. Cocoa Research Institute of Ghana, New Tafo Akim.

Balasimha, D., Daniel, E.V. and Bhat, P.G. (1991) Influence of environmental factors on photosynthesis in cocoa trees. *Agricultural and Forest Meteorology* **55**: 15–21.

Baker, P.S. and Haggar, J. (2007) Global warming: the impact on global coffee. Presentation at the SCAA Conference, Long Beach.

Bale, J.S., Masters, I.D., Hodkinson, C., Awmack, T.M., Bezemer, V.K., Brown, J., Butterfield, A., Buse, J.C., and Coulson, J. (2002) Herbivory in global climate change research: Direct effects of rising temperature on insect herbivores. *Global Change Biology* **8**, 1–16.

Basra, A.S. ed. (2001) Crop Responses and Adaptation to Temperature Stress (2001) Haworth Press.

Bentley, J.W., Boa, E. and Stonehouse, J, (2004) Neighbor trees: shade, intercropping, and cacao in Ecuador. *Human Ecology* **32**:241–270.

Blackburn, F. (1984) *Sugar-cane*. Longman: London. 414 pp.

Boyd, E., N.Grist, S.Juhola and **V. Nelson** (2009) 'Theme Issue: Development Futures in a Changing Climate'. *Development Policy Review*. Vol. 27, No. 6, November 2009. Wiley Blackwell. Editorial: 'Exploring development futures in a changing climate: Frontiers for Development Policy and Practice', p659–674.

Burke, M.B., Lobell, D.B. and Guarino, L. (2009) *Global Environmental Change* **19**: 317-325.

Butt, T.A., McCarl, B.A., Angerer, J., Dyke, P.T. and Stuth, J.W. (2005) The economic and food security implications of food security in Mali. *Climate Change* **68**: 355–378.

Cannon, T (2008) 'Reducing People's Vulnerability to Natural Hazards. Communities and Resilience, Research Paper No. 2008/34, United Nations University, UNU-WIDER. World Institute for Development Economics Research.

Chakraborty, S., Luck, J., Hollaway, G., Freeman, A., Norton, R., Garrett, K.A.,

Percy, K., Hopkins, A., Davis, C. and Karnosky, D.F. (2008) Impacts of Global Change on Diseases of Agricultural Crops and Forest Trees. *CAB Reviews: Perspectives in Agriculture, Veterinary Science, Nutrition and Natural Resources* **3 (**54): 1–15.

Chambers, R., and Pacey, A., and Thrupp, L.A. (1989) 'Farmer first' Intermediate Technology Publications, UK, 1989.

Chancellor, T.C.B and Kubiriba, J. (2006) The effects of climate change on infectious diseases of plants. *Office of Science and Innovation Foresight project on Infectious Diseases: Preparing for the Future*. (Paper T7.2 available in electronic format at: **www.foresight.gov.uk/Infectious Diseases/t7_2a.pdf)**.

Chapin, F. S., Kofinas, G.P., Folke, C. eds (2009). Principles of Ecosystem Stewardship: Resilience-based Natural Resource Management in a Changing World. Springer.

Cheng, W., Inubishi, K., Yagi, K., Sakai, H. and Hasegawa, T. (2009) Interactions of elevated CO_2 and night temperature on rice growth and yield. *Agricultural and Forest Meteorology* **149**: 51-58.

CIAT (International Center for Tropical Agriculture) (2010) Climate change adaptation and mitigation in the Kenyan coffee sector. Report for Sangana Commodities Ltd and the German technical cooperation (GTZ).

Coley, P. (1998). Possible effects of climate change on plant/herbivore interactions in moist tropical forests. *Climatic Change*, **39**, 455–472.

Cowie, J. (2007). *Climate Change: Biological and Human Aspects*. Xvi+487pp, Cambridge University Press.

DaMatta, F.M. and Cochicho Ramalho, J.D. (2006) Impacts of drought and temperature stress on coffee physiology and production: a review. *Brazilian Journal of Plant Physiology* **18**(1) **www.scielo.br/scielo.php?pid=S1677-04202006000100006&script=sci_arttext&tlng=en**.

Dankelman, I. (2002) 'Climate change: learning from gender analysis and women's experiences of organising for sustainable development'. *Gender and Development,* 10 (2) 21-29. Available from: **http://pdfserve.informaworld.com/872626_666_741921472.pdf**.

De Datta, S.K. (1981) *Principles and Practices of Rice Production*. New York: John Wiley & Sons.

De Jesus, W.C., Valadares, R., Cecílio, R.A., Moraes, W.B., de Vale, F.X.R., Alves, F.R. and Paul, P.A. (2008) Worldwide geographical distribution of Black Sigatoka for banana: predictions based on climate change models. *Scientifica Horticulturae* **65**: **www.scielo.br/scielo.php?pid=S0103-90162008000700008&script=sci_arttext&tlng=en)**

De Souza, A.P., Gaspar, M., Da Silva, E.A., Ulian, E.C., Waclawovsky, A.J., Nishiyama, M.Y. Jr, Dos Santos, R.V., Teixeira, M.M., Souza, G.M. and Buckeridge, M.S. (2008) Elevated CO_2 increases photosynthesis, biomass and productivity, and modifies gene expression in sugarcane. *Plant, Cell and Environment* **31:** 1116–1127.

De Souza, R., Borba, B.S.M.C., Da Costa, I.V.L. Pereira, A.O. Jr. and Da Cunha, S.H.F. (2009) The vulnerability of renewable energy to climate change in Brazil. *Energy Policy* **37** (3): 879–889.

Devereux, S. and Edwards, J., (2004) Climate change and food security. IDS Bulletin **35** (3): 22–30, Brighton, Institute of Development studies.

Döll, P. (2002) Impact of climate change and variability on irrigation requirements: a global perspective. *Climatic Change* **54**: 269–293.

Drake, B.G., Hughes, L., Johnson, E.A., Seibel, B.A., Cochrane, M.A., Fabry, V.J., Rasse, D. and Hannah, L. (2005) Synergistic effects. Chapter 18 in Lovejoy, T.E. and Hannah, L. (eds) Climate Change and Biodiversity. Xiii+418pp. Tale University Press, New Haven.

Eakin, H. and Luers, A. L. (2006) Assessing the vulnerability of social-environmental systems, Annu. Rev. Environ. Resour. 31:365–94

Easterling, W.E., P.K. Aggarwal, P.K., Batima, P., Brander, K.M., Erda, L., Howden, S.M., Kirilenko, A., Morton, J., Soussana, J-F., Schmidhuber, J. and Tubiello, F.N. (2007) Food, fibre and forest products. *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK, 273–313.

Eberhart, N. and Smith S. (2008) 'A methodological guide for assessing the impact of Fairtrade' prepared for FLO international.

Ensor, J. and Berger, R. (2009) 'Understanding Climate Change Adaptation. Lessons from community-based approaches'. Practical Action Publishing.

FAO (2007). *'People-centred climate change adaptation: integrating gender issues - Awareness of climate change from a gendered perspective'.* Rome: Food and Agriculture Organization of the United Nations. Available at **ftp://ftp.fao.org/docrep/fao/010/a1395e/a1395e00.pdf**

Few, R., Osbahr, H., Bouwer, L.M, Viner, D. and Sperling, F. (2006) Linking Climate Change Adaptation and Disaster Risk Management for Sustainable Poverty Reduction: Synthesis Report.

Fischer, G., Tubiello, F.N., van Velthuizen, H. and Wiberg, D. (2007) *Technical Forecasting and Social Change* **74**:1083–1107.

Fournier, L.A. and Di Stéfano, J.F. (2004). Variaciones climáticas entre 1988 y 2001, y sus posibles efectos sobre la fenologa de varias especies leñosas y el manejo de un cafetal con sombra en ciudad Colón de Mora, Costa Rica. *Agronomía Costarricense* **28**: 101–120.

Franzen, M. and Mulder, M.B. (2007) Ecological, economic and social perspectives on cocoa production worldwide. *Biodiversity Conservation* **16**: 3835–3849.

Gay, C., Estrada, F., Conde, C., Eakin, H. and Villers, L. (2006) Potential impacts of climate change on agriculture: a case study of coffee production in Veracruz, Mexico. *Climatic Change* **79**: 259–288.

Gbetibouo, G.A. and Hassan, R.M. (2005) Measuring the economic impact of climate change on major African field crops: a Ricardian approach. *Global and Planetary Change* **47**: 143–152.

Ghini, R., Hamada, E., and Bettiol, W. (2008) Climate change and plant diseases. *Scientia Agricola* **65**: **www.scielo.br/scielo.php?pid=S0103-90162008000700015&script=sci_arttext&tlng=en**.

Hannah, L., Lovejoy, T.E. and Schneider, S.H. (2005). Biodiversity and climate change in context. Chapter 1 in Lovejoy, T.E. and Hannah, L. (eds) Climate Change and Biodiversity. Xiii+418pp. Yale University Press, New Haven.

Harrington, R. and Woiwod, I.P. (1995). Insect crop pests and the changing climate. *Weather*, **50:** 200-208.

Hill, M.G. and Dymock, J.J. (1989). *Impact of climate change: agriculture/horticulture systems*. DSIR Entomology Division Submission to the New Zealand Climate Change Programme. Department of Scientific and Industrial Research, Auckland, New Zealand, 16 pp.

Howden, S.M., ois Soussana, J-F., Tubiello, F.N., Chhetri, N., Dunlop, M. and Meinke, H (2007) 'Adapting agriculture to climate change' in **www.pnas.org/content/104/50/19691.full.pdf+html**.

Houghton, J. (2009). *Global Warming: the Complete Briefing*. 4th Edition, xviii+438 pp, Cambridge University Press.

ICCO (2010) International Cocoa Organization. Quarterly Bulletin of Cocoa Statistics, Vol. XXXVI, No. 1, Cocoa year 2009/2010.

IPPC (2007). Intergovernmental Panel on Climate Change, Fourth Assessment Report.

IPCC (2007b) 'Climate Change 2007: Synthesis report, available at: **www.ipcc.ch**.

Jagadish, S.V.K., Craufurd, P.Q. and Wheeler, T.R. (2007) High temperature stress and spikelet sterility in rice (*Oryza* sativa L.). *Journal of Experimental Botany* **58**(7): 1627–1635.

Jain, A. (2009). Global warming and climate change science. Chapter 11 in Hewitt, C.N. and Jackson, A.V. (eds): *Atmospheric Science for Environmental Scientists*. Xiii+ 300 pp, Wiley-Blackwell, Chichester.

James, G. ed (2004) *Sugarcane* 2nd edition. Blackwell: Oxford.

Jaramillo, J., Chabi-Olaye, A., Kamonjo, C., Jaramillo, A., Vega, F.A., Poehling, H-M. and Borgemeister, C. (2009) Thermal tolerance of the coffee berry borer *Hypothenemus hampei*: predictions of climate change impact on a tropical insect pest. *PLoS ONE* **4**(8): e6487. doi:10.1371/journal.pone.0006487.

Jarvis, A., Ramirez, J., Eitzinger, A. and Laderach. P. (2009) Cambio climatico y café en Colombia. Powerpoint presentation accesses at: **www.slideshare.net/CIAT/andy-j-cambio-climtico-en-cafetales-pereira-julio-2009**.

Kigalu, J.M., Kimambo, E.I., Msite, I. and Gembe, M. (2008) Drip irrigation of tea (*Camelia sinensis* L.) 1. Yield and crop water productivity responses to irrigation. *Agricultural Water Management* **95**: 1253–1260.

Lin, E., Wei, X., Hui, J., Yinlong, X., Yue, L., Liping, B. and Liyong, X. (2005) Climate change impacts on crop yield and quality with CO_2 fertilization in China. *Philosophical Transactions of the Royal Society B* **360:** 2149–2154.

Lin, B.B. (2010) The role of agroforestry in reducing water loss through soil evaporation and crop transpiration in coffee agroecosystems. *Agricultural and Forest Meteorology*. In press.

Lobell, D.B. (2007) Changes in diurnal temperature range and national cereal yields. *Agricultural and Forest Meteorology* **145**: 229–238.

Magis, K., (2007) 'Indicator 38 – Community Resilience: Literature and Practice Review. Executive Summary'. Leadership Institute and Portland State University.

Masters, E. (2009) 'Shea producer responses to climate change in Ghana and Burkina Faso: Experiences and Adaptive Measures'. Results of a field survey, June to September, 2009. World Agroforestry Centre (ICRAF), for the Fairtrade Foundation, funded by Comic Relief.

Mbaga-Semgalawe, Z. and Folmer, H. (2000) Household adoption behaviour of improved soil conservation: the case of the North Pare and West Usambara Mountains of Tanzania. *Land Use Policy* **17**(4): 321–336.

McGray, H., Hammill, A., Bradley, R., with Schipper, E.L. and Parry, J-E. (2007) 'Weathering the storm: Options for framing adaptation and development'. World Resources Institute. Available at: **http://pdf.wri.org/weathering_the_storm.pdf** (Accessed 5.06.10).

Moberg, M. (2005) "Fair Trade and Eastern Caribbean Banana Farmers: Rhetoric and Reality in the Anti-Globalization Movement." Human Organization . 64 (1): 4–15

Möller, M. and Weatherhead, E.K. (2007) Evaluating drip irrigation in commercial tea production in Tanzania. *Irrigation and Drainage Systems*: **21**(1): 17–34.

Morgan, J.A., Pataki, D.E., Korner, C., Clark, H., Del Grosso, S.J., Grunzweig, J.M., Knapp, A.K., Mosier, A.R., Newton, P.C.D., Niklaus, P.A., Nippert, J.B., Nowak, R.S., Parton, W.J, Polley, W. and Shaw, M.R. (2004) Water relations in grassland and desert ecosystems exposed to elevated atmospheric CO_2. *Oecologia* **140**: 11–25.

Morton, J (2007) 'The impact of climate change on smallholder and subsistence agriculture'. 19680–19685 _ PNAS _ December 11, 2007 _ vol. 104 _ no. 50.

Morton, J. (2010) 'Strengthening Local Agricultural Innovation in the Face of Climate Change', Presentation to AAA.

Nabi, G. and Mullins, C.E. (2008) Soil temperature dependent growth of cotton seedlings before emergence. *Pedosphere* **18**(1): 54–59.

Naylor, R.L., Falcon, W.P., Rochberg, D. and Wada, N. (2001) Using El Nino/Southern Oscillation climate data to predict rice production in Indonesia. *Climate Change* **50**: 255–265.

Naylor, R.L., Battisti, D.S., Vimont, D.J., Falcon, W.P. and Burke M.B. (2007) Assessing risks of climate variability and climate change for Indonesian rice agriculture. *Proceedings of the National Academy of Sciences* **104**(19): 7752–7757.

Nelson, D., Adger, N. and Brown, K. (2007) Adaptation to Environmental Change: Contributions of a Resilience Framework. Annual Review of Environment and Resources 32, 395–419.

Nelson, V. and Pound, B. (2010) 'A review of the impact of Fairtrade over the last ten years'. Available at: **www.Fairtrade.org.uk/includes/documents/cm_docs/2010/n/2_nri_full_literature_review_final_version.pdf**.

Nelson, V. and Smith, S. (forthcoming) 'Assessing the impact of Fairtrade cotton in Mali, Senegal, Cameroon and India'. A research report from NRI and IDS commissioned by the Fairtrade Foundation.

Nelson, V., Tallontire, A. and Collinson, C. (2002) Assessing the potential of ethical trade schemes for forest dependent people: comparative experiences from Peru and Ecuador. *International Forestry Review* **4,** 99–110.

Nelson, V**.** and T.Stathers (2009) 'Resilience, power, culture and climate: a case study from semi-arid Tanzania and new research directions' *Oxfam Gender and Development Journal, Special Issue on Gender and Climate Change, Vol.17:1, Mar.2009. p81-94*. Also appearing in 'Climate Change and Gender Justice' (2009) ed. Geraldine Terry, Practical Action and Oxfam Publishing.

Nelson, V., Meadows, K., Cannon, T., Morton, J. and Martin, A. (2002) Uncertain predictions, invisible impacts, and the need to mainstream gender in climate change adaptations", *Gender and Development*, 10, 51–59 (also appearing in R Masika (ed.) *Gender, Development and Climate Change*, Oxfam (2002)

NOAA (2010). National Oceanic and Atmospheric Administration **www.esrl.noaa.gov/gmd/ccgg/trends/** accessed, 30 March 2010.

Norby RJ, Sholtis JD, Gunderson CA, Jawdy SS (2003) Fine-root production dominates response of a deciduous forest to atmospheric CO2 enrichment. *Oecologia* **136**: 574–584.

Norris, F.H., S. P. Stevens, B. Pfefferbaum, K.F. Wyche , R.L. Pfefferbaum (2007) 'Community Resilience as a Metaphor, Theory, Set of Capacities, and Strategy for Disaster Readiness'. Journal of Community Psychology (2008) **41**:127–150.

Nowak, R.S., Ellsworth, D.S. and Smith, S.D. (2004) Functional responses of plants to elevated atmospheric CO_2: do photosynthetic and productivity data from FACE experiments support early predictions? *New Phytologist* **162**: 253–280.

Obiefuna, J.C. (1986) The effect of monthly planting on yield, yield patterns and yield decline of plantains (MUSA AAB). *Scientia Horticulturae* **29:** 47–54.

Othieno, C.O., Stephens, W. and Carr, M.K.V. (1992) Yield variability at the Tea Research Foundation of Kenya. *Agricultural and Forest Meteorology* **61**: 237–252.

Owuor, P.O., Wachira, F.N., Ng'etich, W.K. (2010) Influence of region of production on relative clonal plan tea quality parameters in Kenya. *Food Chemistry* **119**: 1168–1174.

Patterson, D.T., Westbrook, J.K., Joyce, R.J.V., Lingren, P.D. and Rogasik, J. (1999). Weeds, insects and diseases. *Climatic Change*, **43**, 711–727.

Peet, M.M. and Wolfe, D. (2000) Vegetable crop responses to climatic change. In: Reddy, K.R., Hodges, H.F. eds *Climate Change and Global Crop Productivity*. pp 213–243. CABI Publishing: Wallingford, UK.

Peet, M.M., Sato, S. and Gardner, R. (1998) Comparing heat stress on male-sterile and male-fertile tomatoes. *Plant, Cell and Environment* **21**: 225–231.

Peng, S., Huang, J., Sheehy, J.E, Laza, R.C., Visperas, R.M., Zhong, X., Centeno, G.S., Khush, G.S. and Cassman, K.G. (2004) Rice yields decline with higher night temperature from global warming. *Proceedings of the National Academy of Sciences* **101**(27): 9971–9975.

Pettengell, C., (2010) 'Climate Change Adaptation. Enabling people living in poverty to adapt'. Oxfam Publications. Available at: **www.oxfam.org.uk/resources/policy/climate_change/downloads/rr_climate_change_adaptation_full_290410.pdf**.

Porter, J.H., Parry, M.L. and Carter, T.R. (1991). The potential effects of climatic change on agricultural insect pests. *Agriculture Forest Meteorology*, **57**, 221–240.

Pritchard, S.G. and Amthor, J.S. (2005) *Crops and Environmental Change: an Introduction to Effects of Global Warming, Increasing Atmospheric CO2 and O3 Concentrations, and Soil Salinization on Crop Physiology and Yield*. Haworth Press.

Purseglove, J.W. (1968) *Tropical Crops: Dicotyledons 2*. Longmans: London.

Radersma, S. and de Ridder, N. (1996) Computed evotranspiration of annual and perennial crops at different temporal and spatial scales using published parameter values. *Agricultural Water Management* **31**: 17–34.

Reddy, K.R., Hodges, H.F. and McKininion, J.M. (1997) Crop modelling and applications: a cotton example. In Sparks, D.L. (ed.) *Advances in Agronomy*, Vol. 59. Academic Press, San Diego, pp. 225–290.

Reddy, K.R., Robana, R.R., Hodges, H.F., Liu, X.J. and McKinnion, J.M. (1998) Interaction of CO_2 enrichment and temperature on cotton growth and leaf characteristics. *Environmental and Experimental Botany* **39**: 117–129.

Reddy, K.R., Hodges, H.F. and Kimball, B.A. (2000) Crop ecosystem responses to climatic change: cotton. In: Reddy, K.R., Hodges, H.F. eds *Climate Change and Global Crop Productivity*. pp. 161–187. CABI Publishing: Wallingford, UK.

Reddy, K.R., Prasad, P.V. and Kakani, P.V. (2005) Crop responses to elevated carbon dioxide and interactions with temperature: cotton. *Journal of Crop Improvement* **13**: 157–191.

Reiter (2008) Global warming and malaria: knowing the horse before hitching the cart. *Malaria Journal* Vol. 7, Supplement 1. **www.malariajournal.com/content/7/S1/S3**.

Resilience Alliance (2007) 'Assessing and managing resilience in socio-ecological systems: A practitioners workbook'. Volume 1, version 1.0. Available online: **www.resalliance.org/3871.php**.

Risbey, J., Milindkandlikar, Hadidowlatabadi (1999) 'Scale, context and decision-making in agricultural adaptation to climate variability and change'. Mitigation and Adaptation Strategies for Global Change, 4: 137–165, 1999. Kluwer Academic Publishers, Belgium.

Robertson, M.J., Inman-Bamber, N.G., Muchowa, R.C. and Wood, A.W. (1999) Physiology and productivity of sugarcane with early and mid-season water deficit. *Field Crops Research* **64:** 211–227.

Robinson, J.C. (1995) Systems of cultivation and management. In: pp. 15–65 *Bananas and Plantains* ed. S. Gowen. Chapman & Hall: London.

Robinson, J.C. and Alberts, A.J. (1989) Seasonal variation in the crop water-use coefficient of banana (cultivar 'Williams') in the subtropics. *Scientia Horticultura* **40**: 215–225.

Rogers, H.H., Bingham, G.E., Cure, J.D., Smith, J.M. and Surano, K.A. (1983). Response of selected plant species to elevated carbon dioxide in the field. *Journal of Environmental* Quality, **12**, 569–574.

Sadava, D., Heller, H.C., Orians, G.H., Purves, W.K. and Hillis, D.M. (2008). *Life: the science of biology*. 8th edition, Sinauer Associates, Sunderland, MA. 1338pp.

Samson, J.A. (1980) *Tropical Fruits*. Longmans, London, pp. 119–161.

Saunders, M.A & Lea, A.S. (2008) Large contribution of sea surface warming to recent increase in Atlantic hurricane activity. *Nature* **451**, 557–560.

Shanks, G.D., Hay, S.I., Stern, D.I., Biomndo, K. and Snow, R.W. (2002) Meteorologic influences on *Plasmodium falciparum* malaria in the highland tea estates of Kericho, Western Kenya. *Emerging infectious diseases* **8**(12): 1404–1408.

Stover, R.H. and Simmonds, N.W. (1987) *Bananas*. Longmans, London.

Tadross, M. A., Hewitson, B.C. and Usman, M.T. (2005). The interannual variability of the onset of the maize growing season over South Africa and Zimbabwe. *Journal of Climate* **18**(16): 3356–3372.

Tao, F., Yokozawa, M., Xu, Y. Hayashi, Y. and Zhang, Z. (2006) Climate changes and trends in phenology and yields of field crops in China, 1981–2000. *Agricultural and Forest Meteorology* **138**: 82–92.

Teodoro A., Klein, A.M. and Tscharntke, T. (2008) Environmentally mediated coffee pest densities in relation to agroforestry management, using hierarchical partitioning analyses. *Agriculture, Ecosystems and Environment* **125**: 120–126.

Thomas, R.J. (2008) Opportunities to reduce the vulnerability of dryland farmers in Central and West Asia and North Africa to climate change. *Agriculture, Ecosystems and Environment* **126**: 36–35.

Thornton, P.K., Jones, P.G., Alagarswamy, G. and Andresen, J. (2008) Spatial variation of crop yield response to climate change in East Africa. *Global Environmental Change* **19**: 54–65.

Thrush, S.F., Hewitt, J.E., Dayton, P.K., Coco.G., Lohrer, A.M., Norkko, A., Norkko, J., and Chiantore, M., 'Forecasting the limits of resilience: integrating empirical research with theory'. *Proceedings of the Royal Society B* 2009 276, 3209–3217 first published online 24 June 2009

Tubiello, F.N., Soussana, J.F. and Howden, S.M. (2007) Crop and pasture response to climate change. *Proceedings of the National Academy of Sciences* **104** (50): 19686–19690.

Vu, J.C.V and Allen, L.H. Jr (2009) Growth at elevated CO_2 delays the adverse effects of drought stress on leaf photosynthesis of the C_4 sugarcane. *Journal of Plant Physiology* **166:** 107–116.

Walker, B.H. (1991). Ecological consequences of atmospheric and climatic change. *Climatic Change*, **18**, 301–316.

Walker, B.H. and Steffen, W. (1997*). The terrestrial biosphere and global change: implications for natural and managed ecosystems*. International Geosphere-Biosphere Programme Secretariat, Stockholm, Sweden, 32 pp.

Wang, H.L., Gan, Y.T., Wang, R.Y., Niu, J.Y., Zhao, H., Yang, Q.G. and Li, G.C. (2008) Pheonological trends in winter wheat and spring cotton in reponse to climate changes in northwest China. *Agricultural and Forest Meteorology* **148**: 1242–1251.

Wijeratne, M.A. (1996) Vulnerability of Sri Lanka tea production to global climate change. *Water, Air and Soil Pollution* **92**: 87–94.

Youkhana, A. and Idol, T. (2009) Tree pruning mulch increases soil C and N in a shaded coffee agroecosystem in Hawaii. *Soil Biology & Biochemistry* **41**: 2527–2534.

Yeates, S.J., Constable, G.A. and McCumstie, T. (2010) Irrigated cotton in the tropical dry season. III: Impact of temperature, cultivar and sowing date on fibre quality. *Field Crops Research* **116:** 300–307.

Yoon, S.T., Hoogenboom, G., Flitcroft, I. and Bannayan, M. (2009) Growth and development of cotton (*Gossypium hirsutum* L.) in response to CO_2 enrichment under two different temperature regimes. *Environmental and Experimental Botany* **67**: 178–187.

Annex 1 Development barriers, promoters and climate change dimensions

Development barriers	Development promoters	Climate Change Dimensions
Population growth	Increasing population density can exhaust resources and increase poverty, but with education and capacity building can sometimes lead to innovation and prosperity	Building adaptive capacity has to include education and support for agricultural innovation amongst many other things, but should take into account both CC scientific and local knowledge. Support for women's education and access to economic opportunities and reproductive health and family planning are important as is support for migrants and resettled populations
Poor infrastructure	Investment in transport, communication and finance	Scaling up and climate-proofing of investment in infrastructure. Communication support is needed on CC awareness and learning
Market access constrained by trade barriers & tariffs, incl. subsidies (the latter favour northern hemisphere investors in agricultural trade and related intellectual property rights)	Pro-poor trade reform urgently required	Pro developing country trade reform is needed for a more equitable context and market access support for smallholders – although the importance of resilience to shocks and stresses and gender implications should be taken into account when considering export trade.
Lack of governance; civic unrest and corruption	Commitment to civic structures, governance, and transparency	Potential for increased conflict over scarce resources (e.g. water in areas of increasing water scarcity) and exacerbation of in-country migration, urbanization and rural-urban food system challenges. Need to build the demand side of governance and social learning on adaptation
Poor agricultural productivity and limited value-added opportunities	Support for innovations in productivity enhancement and post-harvest processing	Rural livelihoods are diverse and location specific, but where negative CC impacts occur support for livelihood protection, intensification and diversification may be required. This might include innovations in farm management to achieve productivity gains, upgrading of roles in value chains to capture added value or may require transformation of livelihood systems. In some cases off farm and new livelihood activities may be required to spread risk and if existing practices become untenable.
Epidemics, human and animal diseases	Health care	Tea, Cotton, Rice Human and plant disease epidemiology will be affected by CC with potential serious human health impacts. Need for scaled up investments in health systems – taking into account CC projections (e.g. 'adaptive health care')
Erratic and poorly resourced environment (climate, soils, water access, genetics)	Buffered environment with resources of light, water, nutrients and genetic materials	Localised processes of environmental degradation have multiple causes and will interact with CC impacts, which themselves may undermine key ecosystem services (provisioning, regulating and cultural services). Ecosystem services contribute to human wellbeing through safety, security, health, material benefits, self-esteem and good social relations (Chapin et al., 2009). More environmentally friendly or agro-ecological farming is likely to improve CC resilience, but has labour and capacity building implications. Need for governmental CC adaptation and disaster risk management planning

Adapted from Kanyama-Phiri, Wellard and Snapp in Snapp and Pound (2008) and authors' own work (third column).

Annex 2 Additional Country-level Climate Projections for 2060s, Africa

Country	Most likely trends in precipitation and seasonal distribution of rainfall by 2060s and/or 2090s	Observed freq. of hot days 1961-1990 (%)	Frequency of hot days by 2060s (%)	Observed freq. of hot nights 1961-1990 (%)	Frequency of hot nights by 2060s (%)	Observed mean % of rainfall falling in heavy events	% age change in rainfall falling in heavy events by 2060s
Benin	Uncertainty on overall rainfall: decreases Jan–June, increases Jul–Dec	11.7	16 - 56	13.8	28 - 72	17.0	-4 - +10
Cameroon	Uncertainty on overall rainfall: increases Sep–Nov	n.a.	20 - 53	13.6	36 - 75	n.a.	-1 - +8
Ethiopia	Increases, especially Oct–Dec in the South; Apr–Sep increases in SW and decreases in	13.8	19 - 40	18.3	29 - 65	n.a.	-3 - +12
Ghana	Uncertainty on overall rainfall: decreases Jan–June, increases Jul–Dec	11.2	18 - 59	13.5	28 - 79	21.8	-4 - +10
Kenya	Increases, especially Jan–Feb and Oct–Dec	13.7	17 - 45	16.1	32 - 75	42.0	-1 - +11
Malawi	Uncertainty on overall rainfall: decreases Jun–Nov, increases Dec–May	12.2	14 - 32	12.0	27 - 53	23.4	-2 - +8
Mali	Uncertainty on overall rainfall, tending towards decreases. Largest decreases in North, and in the SW for Jul–Sep	10.0	18 - 38	13.1	23 - 40	24.4	-9 - +7
Mauritius	Increases more likely in northern islands; decreases more likely in JAS	n.a.	29 - 48	n.a.	29 - 48	n.a.	-6 - +7
Senegal	Uncertainty tending towards decreases	n.a.	22 - 46	11.3	27 - 49	n.a.	-11 - +9
Tanzania	Increases overall, with seasonal patterns varying by region	11.9	19 - 40	11.8	38 - 68	23.6	0 - 11
Uganda	Increases, especially Oct–Dec	14.8	16 - 43	17.7	31 - 84	26.4	0 - 9
Zambia	Uncertainty on overall rainfall, decreases Sep–Nov, increases Dec–Feb, especially in NE	12.4	15 - 29	11.7	26 - 54	23.2	-3 - +8

Source: UNDP Climate Change Country Profiles

Annex 3 Additional Country-level Climate Projections for 2060s, Caribbean/Central America and Asia

Country	Most likely trends in precipitation and seasonal distribution of rainfall by 2060s and/or 2090s	Observed freq. of hot days 1961-1990 (%)	Frequency of hot days by 2060s (%)	Observed freq. of hot nights 1961-1990 (%)	Frequency of hot nights by 2060s (%)	Observed mean % of rainfall falling in heavy events	% age change in rainfall falling in heavy events by 2060s
Belize	Decreases for all seasons	14.0	20 - 55	11.2	30 - 61	17.3	-15 - +6
Cuba	Decreases overall and for all seasons except Sep–Nov	8.9	25 - 61	11.8	31 - 59	n.a.	-9 - +5
Dominican Republic	Decreases especially Jun–Aug	12.5	29 - 72	11.7	33 - 68	n.a.	-20 - +7
Jamaica	Decreases especially Ma–Aug	n.a.	27 - 73	n.a.	29 - 71	n.a.	-14 - +6
Mexico	Decreases for all seasons, especially Dec–Mar	11.6	18 - 34	10.4	22 - 39	24.4	-10 - +4
Nicaragua	Decreases overall, especially Ju–Aug	13.3	25 - 64	11.6	30 - 78	24.5	-18 - +9
Windward Islands							
Dominica	Decreases overall and for all seasons except Mar–May	n.a.	25 - 65	n.a.	24 - 64	n.a.	-18 - +10
St Lucia	Decreases overall and for all seasons	n.a	28 - 67	n.a.	28 - 68	n.a.	-22 - +5
St Vincent	Decreases overall and for all seasons	n.a	31 - 66	n.a.	31 - 75	n.a.	-17 - +6
Vietnam	Increases overall and Aug-Oct; decreases Feb–Apr	11.0	17 - 41	11.4	25 - 51	22.8	0 - +8

Source: UNDP Climate Change Country Profiles

The term 'Windward Islands' is used in trade figures to aggregate trade or production from Dominica, St Lucia, and St Vincent & The Grenadines.

UNIVERSITY of GREENWICH

Natural Resources Institute
University of Greenwich

Medway Campus
Central Avenue
Chatham Maritime
Kent ME4 4TB

Telephone: 01634 883199
Telephone from outside the UK: +44 1634 883199
E-mail: nri@gre.ac.uk
Website: www.nri.org

FS 54723
ISO 9001

THE QUEEN'S ANNIVERSARY PRIZES
FOR HIGHER AND FURTHER EDUCATION
2008

This document is available in other formats on request

D4679-10 May 11