Cranfield UNIVERSITY

What are the projected impacts of climate change on food crop productivity in Africa and S Asia?

DFID Systematic Review

Revised Protocol

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1 Background

Food security is one of this century's key global challenges. By 2050 the world will need to increase crop production to feed its projected 9 billion people. For many developing countries, agriculture is the cornerstone of their economy, the basis of economic growth and main source of livelihood for three out of four of the world's poor (DFID, 2009). DFID (2009) set out a vision of doubling agricultural production in Africa over the next 20 years, and doubling the rate of agricultural growth in South Asia over the same period. This must be done in the face of changing consumption patterns, the impacts of climate change and the growing scarcity of water and land (Royal Society, 2009). which will impact on the drive for increased productivity in many developing nations, and hamper progress to meeting specific Millennium Development Goals (MDG 1). The vision to enhance agricultural productivity in Africa and South Asia thus needs to be in ways that manage natural resources sustainably and are adapted to climate change.

Although agricultural production is sufficient to meet current food demands, 1 billion people are still undernourished. Many of the poorest producers farm in locations where the climate is already marginal for production (CCAFS, 2009) and farmers with limited access to agricultural knowledge and technology will also be less able to adapt their farming practices to climate change. For these reasons, the poorest farmers are those most vulnerable to the potential impacts of climate change. Despite international negotiations to reduce greenhouse emissions (GHG), a 20-30 year lag in our global climate system means we are already committed to a world that will be 0.6^{o}C warmer, with associated changes in rainfall patterns, by the end of the century (IPCC AR4 Report, 2007). Future crop production will thus have to adapt to changes in climate to which we are already committed.

Many studies in the research literature describe how agriculture in Africa will be one of the sectors most vulnerable to climate change and variability (Slingo et al., 2005). This is because a significant proportion of the African economy is dependent on agriculture (Benhin, 2008), most of Africa's water (85%) is used for agriculture (Downing et al., 1997), farming techniques are relatively primitive and the majority of the continent is already hot and dry. Spatial and temporal changes in precipitation and temperature patterns will shift agro-ecological zones (Kurukulasuriya and Mendelsohn, 2008) and thus have major impacts on the viability of both dryland (Challinor et al., 2005) and irrigated farming (Knox et al., 2010).

Similarly, agriculture is critical to South Asia's development. More than 75 percent of the region's poor live in rural areas and are dependent on rainfed agriculture, livestock, and fragile forests for their livelihoods. The Green Revolution increased food grain productivity, improved food security and rural wages bringing a significant reduction in rural poverty. But the challenge now is to replicate and sustain these achievements in the future with a more variable and unpredictable climate (World Bank, 2009).

The constraints on food crop production and distribution differ between regions and, in particular, between industrialised and developing countries. Climate change has the potential to exacerbate the stresses on crop plants, potentially leading to catastrophic yield reductions. It is likely to affect hydrological water balances, the availability of fresh water supplies for irrigation and soil moisture balances, with consequent impacts on agricultural productivity. Soils are another essential but non-renewable resource for food crop production so maintaining soil fertility, health and nutrient availability is vital. Significant losses in crop yields also occur through pests, diseases and weed competition, accounting for major inefficiencies in resource use (water, fertiliser, energy and labour). Reducing these losses represents one of the most accessible means of increasing food supplies.

Climate change will aggravate the effects on crops of stresses such as heat, drought, salinity and submergence in water (Kang et al, 2009). Lobell et al. (2008) conducted an analysis of these climate risks for crops in 12 food-insecure regions to identify adaptation priorities based on crop models and climate projections for the 2030s. Their analysis reinforced the importance of improved crop

germplasm (based on access to and use of crop genetic resources collections) and improved agronomic practices as a strategy for climate change adaptation in agriculture, and that a few target crops will be particularly vulnerable in different regions. Adaptation strategies for these crops must be carried out in the face of other constraints such as labour shortages and rising energy costs.

As climate is a primary determinant of agricultural productivity, any significant changes in climate in the future will influence crop and livestock productivity, hydrologic balances, input supplies and other components of managing agricultural systems. However, the nature of these biophysical effects and human responses are complex and uncertain (Adams et al., 1998). In this context and particularly the need to focus more on evidence-informed decision making, DFID commissioned Cranfield University to undertake a Systematic Review (SR) of the impacts of climate change on agricultural productivity in Africa and South Asia. The review will inform DFID policy and practice options, including resource allocation, for agricultural systems in these areas under a changing climate.

This Protocol defines the framework for the SR including the objectives, data search and extraction strategies, approaches for data synthesis and analysis. The review will have broader international relevance to those engaged in climate change impact assessments on agriculture and natural resources management.

2 Review objective and primary question

As in all systematic reviews, one of the most important aspects is the formulation of the primary question. But defining the question is inevitably a compromise between taking a holistic approach, involving a large number of variables and relevant studies, and a reductionist approach that limits the review's relevance, utility, and value (Pullin et al., 2009). The subject of climate change impacts on agriculture falls into the former category as the available literature is vast, so it is essential to frame the question very carefully to focus the review but without limiting its external credibility. Thus the primary research question for this SR will be:

“What are the projected impacts of climate change on food crop productivity in Africa and S Asia?”

The terms ‘adaptation’ and ‘agriculture’ have been omitted from the primary question as these would excessively broaden the scope of the SR – the adaptation of agriculture to climate change is itself a separate discipline and ‘agriculture’ could be interpreted to include aspects such as livestock production and forestry. This SR will focus specifically on the biophysical aspects of crops and the impact that climate change might have on crop productivity (i.e. yield per unit area).

Similarly, the review will not consider ‘food production’, as this is dependent on non-biophysical factors, such as investment in irrigation, international trade policy and world market prices. Nor will it consider the impact of climate related ‘shocks’ (flood, drought, pest attacks) on food production.

Following SR convention, the research question needs to be broken down into components (PICO/PECO) (Table 1).

Table 1 Breaking down the research question (PICO/PECO).

PICO/PECO	Description
Population	Agriculture – narrow down to food crops. Exclude grassland, fibre, commodity / industrial crops, fruit, and vegetables Crops included in review: Rice, wheat, maize, sorghum, millet, cassava, yams, plantain, and sugarcane. These are the most important crops accounting for 80% of total production in Africa and S Asia based on FAO STAT, see Annex 1) Africa and S Asia: Study will include all African countries, rather than selected areas (e.g. Sub-Saharan Africa) or only DFID target countries. In this review S Asia will include India, Pakistan, Bangladesh, Sri Lanka, Nepal, Bhutan and Afghanistan
Intervention	Climate change is the intervention as projected by various GCMs Time-scale to be used is from the current (2010) up to the 2050s Climate variables to be included are temperature (mean, seasonal variation) and rainfall (mean annual and seasonality) Changes in $C0_2$ concentration will be included
Comparator	Baseline climate, typically 1961-90 (note there will be other defined 'baselines' reported in the literature which may constitute an 'effect modifier'
Outcome	Change in average yield and change in variability of yield Change in irrigation need Change in fertilizer / pesticide need Change in crop suitability / sustainability

3 Methodology

There is extensive literature on climate change impacts and agriculture in the academic and public domains. This review will not repeat existing reviews recently conducted by the IPCC (2007), IAASTD (2009) and others, but it will of course need to consider the evidence from these studies. This review will include a poverty reduction / development focus which has not yet been considered in previous climate change and agriculture reviews. The boundaries of this review will include:

- biophysical studies only, recognising that agriculture is practiced within an economic and social context that is often location-specific;
- studies that only use climate projections, or that study past climate events, but not those concerned with the underlying science of the response of crops and animals to one or more climate factors;
- studies that focus on productivity of food crops and the sustainability of food systems from one year to the next, and;
- studies that focus on crop productivity, omitting the forestry, fisheries, livestock and other non-food crop agricultural sectors.

The SR will evaluate the potential for using a production system/agro-ecological zone classification to group evidence - for example, high potential zones, hillside environments, semi-arid regions may be used to provide generic conclusions from the evidence. There are risks with up-scaling evidence from case studies, but the review team will work closely with DFID regarding the definition of suitable agoclimatic / agroecological zones and appropriate definition of agricultural systems.

It is important to note at this stage, that this topic is not ideally suited to a systematic review in its usual form. The approach is generally used to synthesise results from experimental trials. In this case, by definition, it is impossible to evaluate the impact of future climate on agriculture through experimentation. Scientific studies of the topic will inevitably be based on models; both of climate and crop response. As the number of models available to do this is limited there is a danger that the results of a meta-analysis are biased by assumptions made in the models. Therefore, a truly systematic review is not possible, however, subject to this caveat the systematic review approach will be applied as far as possible.

3.1 Search strategy

The main database sources, search websites and organisation websites to be used in the review are summarised in Table 2. This list is not necessarily exhaustive, as others will be identified during the scoping study. Academic database sources will be sampled first, to avoid duplication later from less specialised databases. During the full review, a maximum of 50 'hits' will be considered from each search website. The search terms to be used in the review are summarized in Table 3.

Table 2 Database sources and websites.

Database sources	Search websites	Organisation websites
ISI Web of Knowledge (WoK)	google.com	World Bank
Scopus	googlescholar.com	FAO
EBSCO GreenFILE	dogpile.com	Resources for the Future
CSA Natural Sciences	scirus.com	World Bank
Directory of Open Access Journals		Consultative Group on International Agricultural Research (CGIAR)
ScienceDirect		International Water Management Institute
Ingenta Connect		Asian Development Bank
InTute		Climate Institute
FAO Corporate Document Repository		Centre for Environmental Economics and Policy in Africa
		Science and Development Network
		International Fund for Agricultural Development (IFAD)

Table 3 Summary of search terms to be used in review.

Population, Subject	Interventions	Comparators	Outcomes
Agriculture	Climate change		Yield
Crop	Temperature		Fertiliser
Wheat	CO_2		Irrigation
Rice	Rainfall		Crop failure
Maize			Disease
Millet			Drought
Cassava			Soil degradation
Sorghum			Salinity
Millet			Farm income
Yam			
Plantain			
Sugarcane			

All references retrieved from the computerised databases (WoK etc) will be exported into a bibliographic software package (Refworks) prior to assessment of relevance using inclusion criteria. The bibliographies of included material will also be searched for relevant references. Only literature published in English will be reviewed, foreign language searches will not be carried out. Searches will be limited to sources published from 1990 onwards.

Regional terms (such as “Africa” or “South Asia” and specific countries will not be used as search terms, as this may restrict the search and exclude studies that have taken a wider or global perspective. Instead, these will be screened later using the “inclusion criteria” (see below). Searches were trialled using the following English language search terms (*and ? denote wildcards).

Table 4 Search terms trialled in Web of Science (25 Aug 2010) and number of hits.

Search term	All in title	CC in title	All in topic	Comments
“Climate change” AND Agricultur*	296	922	3,297	Search term is too broad as agriculture encompasses food and non-food (e.g. forestry) production as well as livestock. It also includes mitigation aspects of climate change and agriculture which are not relevant to this SR
“Climat* change” AND Agriculture AND Adapt*	20	253	498	As above (too general), but includes adaptation
“Climat* change” AND crop* AND Adapt*	17	**217**	492	Good search which captures crop related adaptation
“Climate change” AND Agricultur* AND (Temperature OR Rain* OR CO2)	9	479	1,536	Inclusion of secondary intervention terms makes search too specific
“Climate change” AND (Yield OR Fertili?er OR Irrigation OR Failure OR Disease OR Drought OR Soil OR Salinity)	**410**	2,081	10,461	A good search which captures the key impacts of climate change on crop productivity
“Climate change” AND crop*	170	601	1,540	Search term too broad
“Climate change” AND (Rice OR wheat OR maize OR sorghum OR millet OR cassava OR yam* OR plantain* OR sugar*)	160	**338**	1,384	A good search if the secondary terms are included in the topic
“Climate change” AND (Yield OR Fertili?er OR Irrigation OR Failure OR Disease OR Drought OR Soil OR Salinity) AND (Rice OR wheat OR maize OR sorghum OR millet OR cassava OR yam* OR plantain* OR sugar*)	37	273	989	Included in above search
“Climate change” AND “farm* income”	0	7	18	Too restrictive search term with too few hits for meta-analysis.

The Searches given in **bold** are those proposed for use in this SR

3.2 Study inclusion criteria

All literature retrieved will be screened for relevance using the study inclusion criteria given below.

Relevant subjects:

- Any countries / regions in Africa and S Asia (as defined above)
- Any scale from field to region
- Any crops (as defined above).
- Include small-scale and commercial agriculture.

Type of intervention:

- Climate change emission scenarios for time slices up to the 2050s;
- Emission scenarios based on IPCC scenarios;
- Projected changes in mean, total or seasonality;

Comparator:

Compares future outcomes with present / baseline outcomes;

Method:

Controlled experiments or biophysical modelling

Outcomes:

Studies that consider the change in crop suitability, performance, variability, sustainability.

The published date of literature to be included in the SR is an important feature as GCMs and emissions scenario are continually being updated. For this SR, any literature preceding publication of the Third IPCC Assessment Report (IPCC, 2001) will be excluded.

The initial filtering will be undertaken based on the title of the literature source; a second filter will then be used based on the content in the abstract, and then only the full text reviewed for those articles, reports and papers that pass all criteria. This stage will be undertaken by 2 researchers, working independently, to screen the literature datasets. A cross comparison will then be completed to ensure consistency between the researchers in the acceptance/rejection criteria being applied.

3.3 Potential effect modifiers and reasons for heterogeneity

Systematic reviews are generally best applied to studies where there is good primary data. However, this review will be limited to assessing the modelled outputs from a wide range of climate change impact studies, all of which will inevitably contain a number of 'effect modifiers', including:

- Alternative general circulation models (GCM)
- Different emission scenarios and ensembles
- Different crop varieties and husbandry techniques
- Different agroecological conditions
- Varying methods of irrigation and levels of mechanisation

The extent to which these effect modifiers are present in each study will impact on whether a robust meta-analysis will be possible. For some crop types (e.g. rice) there may be sufficient data available, but the meta-analysis will need to take into account the effect of these modifiers.

3.4 Study quality assessment

To avoid bias, care will need to be exercised in interpreting studies reporting climate change impacts across similar agricultural systems but conducted using different methodologies, as there is no single discriminator that can be used to determine which model/approach is best. For example, contrasting crop models, model parameterisation, calibration and validation, the use of different models/methods for GCM downscaling and the appropriateness of temporal and spatial scales, will all have an impact on the reported outputs, and hence result in high potential for bias where low quality data might have been used.

In other disciplines, a 'hierarchy of research methodologies' is typically used to score data in terms of its scientific rigour. This approach will not work in this SR because the environmental context of each study provides too much 'internal' variability. Climate change studies are intentionally conducted at river basin or region levels, and not designed to be comparable to other studies. The data will therefore be assessed against whether they use recognised crop models, GCMs, data sources and emissions scenarios. A relative weighting or scoring will be used to rank data depending on whether they are from quantitative peer reviewed outputs (high ranking), or from grey literature (e.g. reports, in-country case studies, technical bulletins) or other sources (e.g. internet) (low ranking). Qualitative research will be rejected from the SR.

3.5 Data extraction strategy

It is anticipated that a wide range of empirical data will be identified, ranging from detailed case studies (catchment/region) using regional downscaling (RCM) to broad-scale national assessments using single GCM outputs and spatial (GIS) modeling. The approach will be to extract all relevant data based on the 'outcome' search terms and inclusion criteria, and then to tabulate the information by crop type and region using spreadsheets (MS Excel). The data extraction process will be carefully documented for transparency, reporting any reasons for data heterogeneity.

3.6 Data synthesis and presentation

This SR will be based on a narrative synthesis but with some quantitative evidence, where possible. A narrative approach is more suited to studies such as climate change impacts where the subject content is broad and the range of potential outcomes disparate. However, any quantitative synthesis that can be undertaken using available data will be presented to support the narrative. For example, it may be feasible to apply meta-analysis (box plots) to some crop types (e.g. climate change impacts on yield variability of rice and sugarcane in Asia) if sufficient data are available. The narrative synthesis will also include quantitative data (presented as tables with means, medians and SD) for particular crop/climate scenarios. One major advantage of the narrative approach is the potential to highlight to DFID (and others) the gaps in knowledge that exist in this subject, and areas suitable for targeting future programme development.

3.7 Scoping study and protocol updating

Whilst the SR Protocol is undergoing peer review, a scoping study will be undertaken (July) to test the search strategy and gauge the scale of available literature based on the search terms (Table 2). Following peer review, the scoping study and feedback from DFID, the protocol will be updated and the full SR will commence.

3.8 Potential sources of conflict and sources of support

There are no known sources of conflict. The study is funded by the UK Department of International Development (DFID).

3.9 Project timeframe

In accordance with the Project Schedule, the following actions and dates have been defined:

1. Complete and submit a systematic review protocol for peer review (20th July 2010).
2. Complete and submit full draft systematic review (30th September 2010).
3. Produce final systematic review incorporating DFID and external peer review comments (30th October 2010).
4. Produce 2 short summaries, comprising (i) 1000 word brief targeted at DFID stakeholders and (ii) 200 word summary suitable for on-line dissemination (15th November 2010).

4 References

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5 Review team and contacts

The review team comprises of 3 members of staff from Cranfield University:

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Dr Andre Daccache (Research Fellow) a.daccache@cranfield.ac.uk

Knox will lead the project and liaise with the DFID Co-ordinator. Knox and Hess will draft the Protocol. Daccache will be responsible for information retrieval, synthesis and where possible the meta-analysis. Knox and Hess will be responsible for co-ordinating and drafting the SR and responding to DFID and peer review feedback at the Protocol and Draft SR stages. Knox will finalise the SR and ensure project milestones and outputs are delivered on schedule.

6 Annex 1: Crop production in Africa and South Asia

Table 5 Summary of top 10 most important crops grown in Africa (East, West, Central, and South) based on value ($1000) and production (MT). Source derived from FAO STAT (2010).

Crop type	Production (Int $1000)	Production (MT)	Production (%)
Cassava	7498974	114011873	27
Sugar cane	1148239	56411295	13
Yams	7171966	44229359	10
Maize	3760233	40817124	10
Plantains	4886560	24548008	6
Sorghum	2070936	19061034	5
Millet	2169395	14854303	4
Rice (paddy)	2915370	13947263	3
Vegetables (fresh)	2203201	11804598	3
Other	20690706	81852365	19
Total	**54515580**	**421537222**	**100**

Table 6 Summary of top 10 most important crops grown in South Asia based on value ($1000) and production (MT). Source derived from FAO STAT (2010).

Crop type	Production (Int $1000)	Production (MT)	Production (%)
Sugar cane	8162910	425196844	45
Rice (paddy)	41671090	206210377	22
Wheat	16754200	120846418	13
Potatoes	4926446	43230669	5
Vegetables(fresh)	6756402	36009709	4
Bananas	3285574	24500404	3
Onions, dry	2396308	16716723	2
Mangoes, guavas	3949902	16222031	2
Tomatoes	3378348	15759936	2
Other	18109551	42947629	5
Total	**109390731**	**947640740**	**100**