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

DFID Systematic Review

Final Report

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Executive Summary

In many developing countries, agriculture is the cornerstone of their economy, the basis of economic growth and the main source of livelihood. But agriculture in the developing world is often cited as being one of the sectors most vulnerable to climate change. In Africa, for example, the majority of available fresh water is used for agriculture; farming techniques are relatively simple; and much of the continent is already hot and dry. Any changes in precipitation and temperature patterns will thus have major impacts on the viability and yields in crop production. To exacerbate the situation, recent studies warn of an unprecedented confluence of pressures on agriculture – with population growth and development driving up global demand for food and competition for land, water and energy intensifying as the impacts of climate change starts to take effect. In this context, any strategy to enhance agricultural productivity in Africa and South Asia needs to ensure that natural resources are managed sustainably and adapted to climate change.

In order to inform policy and practice options, including resource allocation, DFID commissioned Cranfield University to undertake a Systematic Review (SR) of the impacts of climate change on crop productivity in Africa and South Asia. This report summarises that review, and provides a detailed account of the protocol and methodology, data collection, meta-analyses and synthesis. The project commenced in June 2010 and was completed in March 2011. The review focussed on eight food crops, namely rice, wheat maize, sorghum, millet, cassava, yam, plantain and sugarcane, which collectively account for over 80% of total agricultural production in Africa and South Asia. A protocol was produced detailing the methodology; search strategy and search terms; study inclusion criteria; database sources; and approaches for data synthesis and presentation. For this, the authors followed the Guidelines for Systematic Reviews in Environmental Management developed by the Centre for Evidence Based Conservation (CEBC) (CEE, 2010). After completing the searches of published and grey literature, 1144 sources were identified. These were ultimately filtered down to 53 based on title and abstract screening (representing 257 observations).

For each crop and region, data were extracted on the projected impacts of climate change on crop productivity (principally yield) expressed as a yield “variation” (that is projected yield for the given future scenario as a percentage of current, or baseline, yield). The review was constrained to studies using bio-physical models for impact assessment rather than statistical sensitivity analyses. Following an initial scoping, a narrative synthesis with quantitative evidence was proposed. Various meta-analyses were subsequently undertaken, although the results need to be interpreted with caution given the wide range of ‘effect modifiers’. These include, for example, the use of different general circulation models (GCM), downscaling approaches, emissions scenarios, crop varieties, husbandry techniques, agro-ecological conditions and reported scale of enquiry (local to regional). The reported yield variations thus inevitably include both the potential impacts of climate change as well as the effect of many other factors implicit in the studies. Notwithstanding these limitations, the key findings are summarised below, and for all crops and by region overleaf (Tables 1 and 2).

- A mean overall reduction (-8%) in crop yield due to climate change was identified, with significant variations for wheat (-12%), maize (-7%), sorghum (-13%) and millet (-9%);
- The yield impacts were crop-specific in S Asia and Africa. In S Asia, crops with significant yield variation included maize (-16%) and sorghum (-11%). In Africa, the crops with significant yield variation included wheat (-17 %), maize (-5%), sorghum (-15%) and millet (-10%);
- For rice the mean yield variation (-3%) was not statistically significant, regional differences were strongly influenced by the small number of studies for Africa, and there was no consistent message regarding potential impact of climate change on rice yield over time;
- As the climate signal increases, the yield impact increases; however, only projected variations for the 2050s and beyond were found to be statistically significantly different from zero, and;
- For cassava, sugarcane and yams there were too few studies to comment on whether there were any significant yield impacts or any regional differences.

Table 1 Summary of reported impacts of climate change on yield for (i) all crops, (ii) for S. Asia and (iii) Africa, by region.

Crop	n	Mean variation (%)	Crops with significant variation	n	Mean variation (%)	Crops with non-significant variation[1]	n
All crops	257	-7.7	Wheat Maize Sorghum Millet	37 129 23 9	-12.1 -7.2 -13.0 -8.8	Rice Cassava Sugarcane	43 8 7
S Asia	94	-7.7	Maize Sorghum	23 10	-15.9 -10.8	Rice Wheat Sugarcane	38 17 4
South Asia	74	-8.7	Maize Sorghum	21 10	-17.6 -10.8	Rice Wheat Sugarcane	26 13 3
South East Asia	20	-3.6 (NS)	-	-	-	Rice Wheat Maize	12 4 2
Africa	163	-7.7	Wheat Maize Sorghum Millet	20 106 13 8	-17.2 -5.4 -14.6 -9.6	Rice Cassava Sugarcane	5 7 3
Central Africa	14	-14.9	Maize	8	-13.1	Wheat	2
East Africa	35	0.4 (NS)	-	-	-	Wheat Maize	2 29
North Africa	22	0.8 (NS)	-	-	-	Wheat Maize	10 12
Sahel	24	-11.3	Maize Millet	13 6	-12.6 -10.6	Sorghum	3
Southern Africa	33	-11.0	Maize	24	-11.4	Wheat Sorghum Sugarcane	2 3 2
West Africa	34	-12.5	Maize	19	-7.4	Wheat Sorghum Cassava	3 5 4

Notes

1. See Appendix for a list of countries included within each region;
2. n = number of reported mean yield variations. This may include several from the same source for different countries or time-slices; NS – not significant.
3. Significance tested at 0.05% level by comparing the confidence interval of the mean with a zero response;
4. Data was not necessarily available for all crops in all regions

[1] Only crops with more than one observation included.

Table 2 Summary of reported impacts of climate change on yield in Africa and S Asia, for (i) all crops, (ii) C3 and C4 crops, and (ii) individual crop types.

Crop	**n**		**Mean variation (%)**	**Overall variation**	**Regional differences**	**Time-slice**
	S Asia	**Africa**				
All crops	94	163	-7.7	**An overall reduction in crop yield due to climate change.**	**The projected variation for both S Asia (-7.7%) and Africa (-7.7%) is significant.**	**Only projected variations for 2050s and beyond are significantly different from zero.**
C3 crops[2]	56	33	-7.3	**An overall reduction in crop yield due to climate change.**	**A significant negative mean variation for Africa (-12.7%).** Not significant for S Asia.	**Only projected variations for 2030s and 2050s are significantly different from zero.**
C4 crops[3]	38	130	-7.9	**An overall reduction in crop yield due to climate change.**	**A significant negative mean variation for S Asia (-13.0%) and Africa (-6.4%).**	**Only projected variations for 2050s and beyond are significantly different from zero.**
Rice	38	5	-2.8 (NS)	No significant response. Some sources (40%) project an increase and some (60%) a decrease in mean yield and for several, the range of projections straddle the "no effect" line.	Variability in projections is smaller for Africa than for S Asia, although this largely reflects a smaller number of studies.	No consistent message.
Wheat	17	20	-12.1%	Average response is negative, but some project –^{ve} and others +^{ve} mean variation, and for several the range of projections straddles the "no effect" line.	**A significant negative mean variation for Africa (-17.2%).** Not significant for S Asia.	Too few studies have considered all time slices to comment

[2] Cassava, Rice, Wheat and Yam
[3] Maize, Millet, Sorghum and Sugarcane

Crop	n		Mean variation (%)	Overall variation	Regional differences	Time-slice
	S Asia	Africa				
Maize	23	106	-7.2	**An overall reduction in crop yield due to climate change.**	**A significant variation for both S Asia (-15.9%) and Africa (-5.4%).** Greater range of projections in eastern and southern Africa, possibly due to greater number of studies.	**Only projections beyond 2050s are significantly different from zero.**
Sorghum	10	13	-13.0	**An overall –^{ve} mean variation** although the projected range of some straddles the "no effect" line.	**Significant for both Africa and S Asia.**	The results of the few studies suggest a **significant impact for 2080s only.**
Millet	1	8	-8.8	**An overall –^{ve} mean variation** although the projected range of some straddles the "no effect" line.	**A significant variation for Africa,** but too few studies to comment on S Asia.	Too few studies to comment.
Cassava	1	7	-9.4 (NS)	No significant response. Most studies project an overall –^{ve} mean variation although the projected range of some straddles the "no effect" line. One study projected an overall +^{ve} mean variation.	Too few studies to comment.	Too few studies to comment.
Sugarcane	4	3	-1.6 (NS)	No significant response. Some sources project an increase and some a decrease in mean yield and for several, the range of projections straddle the "no effect" line.	Too few studies to comment.	Too few studies to comment.
Yams	0	1	-5.0 (NS)	Too few studies to comment.	Too few studies to comment.	Too few studies to comment.

Notes:

1. See Appendix for a list of countries included within each region;
2. n = number of reported mean yield variations. This may include several from the same source for different countries or time-slices; NS – not significant.
3. Significance tested at 0.05% level by comparing the confidence interval of the mean with a zero response;
4. Data was not necessarily available for all crops in all regions.

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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 help inform DFID policy and practice options, including resource allocation, for agricultural systems in these areas under a changing climate. This report summarises the systematic review that has been undertaken. It includes a detailed account of the protocol and methodology, the data extraction strategy, data collection, meta-analyses and synthesis of results. The project commenced in June 2010 and was completed in January 2011. The study followed the Guidelines for Systematic Reviews in Environmental Management developed by the Centre for Evidence–Based Conservation (CEBC) for the Collaboration for Environmental Evidence (CEE, 2010).

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’ were 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 3).

Table 3 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 has not repeated existing reviews conducted by the IPCC (2007), IAASTD (2009) and others, but of course needed to consider the evidence from these studies. The boundaries of the review included:

- 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.

It is important to note, 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.

3.1 Search strategy

The main database sources, search websites and organisation websites used in the review are summarised in Table 4. Academic database sources were sampled first, to avoid duplication later from less specialised databases. During the review, a maximum of 50 'hits' were considered from each search website. The search terms used in the review are summarized in Table 5.

Table 4 Database sources and websites.

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

Table 5 Summary of search terms used in the systematic review.

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

All the references retrieved from the various computerised databases (WoK etc) were then exported into a bibliographic software package (Refworks) prior to assessment of relevance using the inclusion criteria. The bibliographies of that material were also searched for any relevant references. Only literature published in English was reviewed. Searches were limited to sources published from 1990.

Regional terms (such as "Africa" or "South Asia" and specific countries were not used as specific search terms, as these could restrict the search and exclude studies that have taken a wider or global perspective. Instead, these were screened later using the 'inclusion criteria'. Searches were initially trialled during the protocol phase using the following English language search terms (*and ? denote wildcards) (Table 6).

Table 6 Search terms trialled in Web of Science (25 Aug 2010) and reported 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** represent those ultimately used in the systematic review

3.2 Study inclusion criteria

All the literature retrieved was then screened for relevance using the following 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 considered the change in crop suitability, performance, variability and/or sustainability.

The published date of literature included in the review was an important feature as GCMs and emissions scenario are continually being updated. For this review, any literature preceding publication of the Third IPCC Assessment Report (IPCC, 2001) was excluded. The initial filtering was undertaken based on the title of the literature source; a second filter was then based on the content in the abstract, and then only the full text reviewed for those articles, reports and papers that passed all inclusion criteria. This stage was undertaken by 2 researchers (Knox and Daccache), working independently, to screen the literature datasets. A cross comparison was then 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 was limited to assessing modelled outputs from a wide range of climate change impact studies, all of which will inevitably contained a number of 'effect modifiers', including:

- Alternative general circulation models (GCM);
- Different emission scenarios and ensembles;
- Different crop varieties and husbandry techniques;
- Different agro-ecological conditions, and;
- Varying assumed methods of irrigation and levels of mechanisation/crop husbandry

3.4 Study quality assessment

To avoid bias, care needed 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 and methods for GCM downscaling and the appropriateness of temporal and spatial scales, will all inevitably 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' has typically been used to score data in terms of scientific rigour. This approach did not work in this review 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 intentionally designed to be comparable to other studies. The data was therefore assessed against whether they used recognised crop models, GCMs, data sources and emissions scenarios. Qualitative research was not included.

3.5 Data extraction strategy, synthesis and presentation

Following the literature searches, a wide range of empirical data was identified, ranging from data form detailed case studies (catchments/regions) using regional downscaling (RCM) to much broader scale assessments using single GCM outputs and spatial (GIS) modeling. The approach used was therefore to extract all relevant data based on the 'outcome' search terms and inclusion criteria, and then to collate the information by crop type and region using spreadsheets (MS Excel). From these data, the meta-analyses were then conducted. Originally, the review was to be based on a narrative synthesis supported by quantitative evidence. This approach was considered to be suited to studies such as climate change impacts where the subject content is broad and the range of potential outcomes disparate. However, following the data extraction phase it was apparent that some meta-analyses were possible (see Results Section 5.3).

3.6 Scoping study and full review

The SR protocol was drafted and reviewed by DFID in Summer 2010. A scoping study was then undertaken to test the search strategy and gauge the scale of available literature based on the search terms. Based on the scoping study and feedback from DFID, the protocol was updated and the full SR implemented. This was completed in December 2010.

3.7 Potential sources of conflict and sources of support

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

4 Results

4.1 Summary analysis of the literature reviewed

The relevant literature was selected and screened in four stages (Figure 1):

1. Using the agreed keywords and databases, relevant literature was identified and assembled in a database (RefWorks).
2. Duplicates were removed, leaving a total of 1,114 unique sources that matched the search criteria.
3. Sources were screened on the basis of title to remove those that clearly did not meet the inclusion criteria, reducing the total to 333.
4. A similar screening was carried out on the basis of abstracts leaving a total of 52 relevant sources that met the inclusion criteria (this included 256 independent observations for analysis).

Figure 1 Schematic overview of the individual stages in the systematic review.

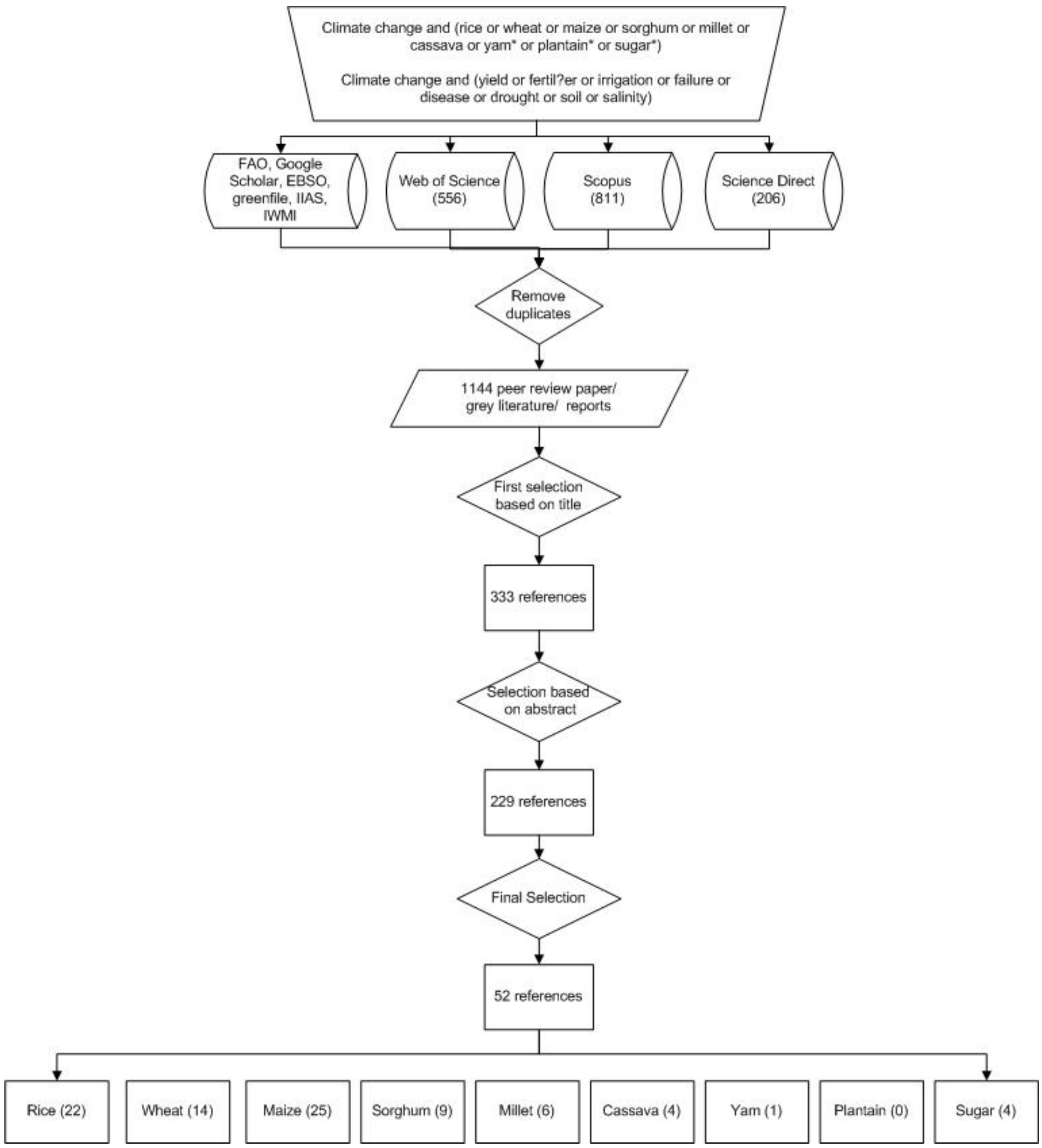


Figure 2 shows the number of sources (papers, reports and grey literature) reviewed at each stage of the data screening. The final set of sources was dominated by papers focussing on rice, maize and wheat and cassava, yam, sugarcane and plantain were the crops with the lowest number of references. This highlights an important knowledge gap where resources could be focussed to help rebalance the level of understanding of climate change impacts in particular cropping systems.

Figure 2 Number of references identified and filtered at each screening stage.

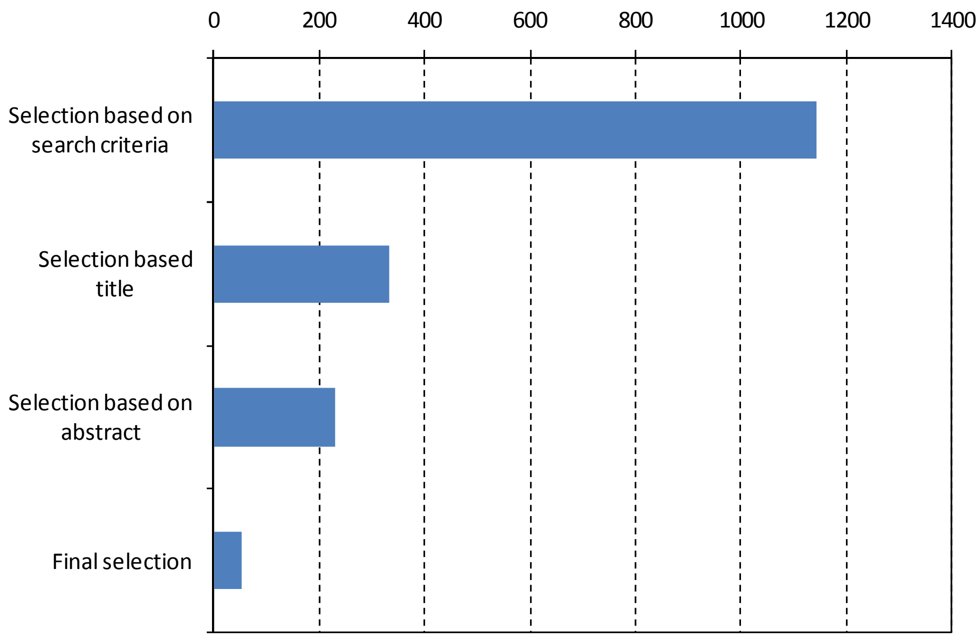


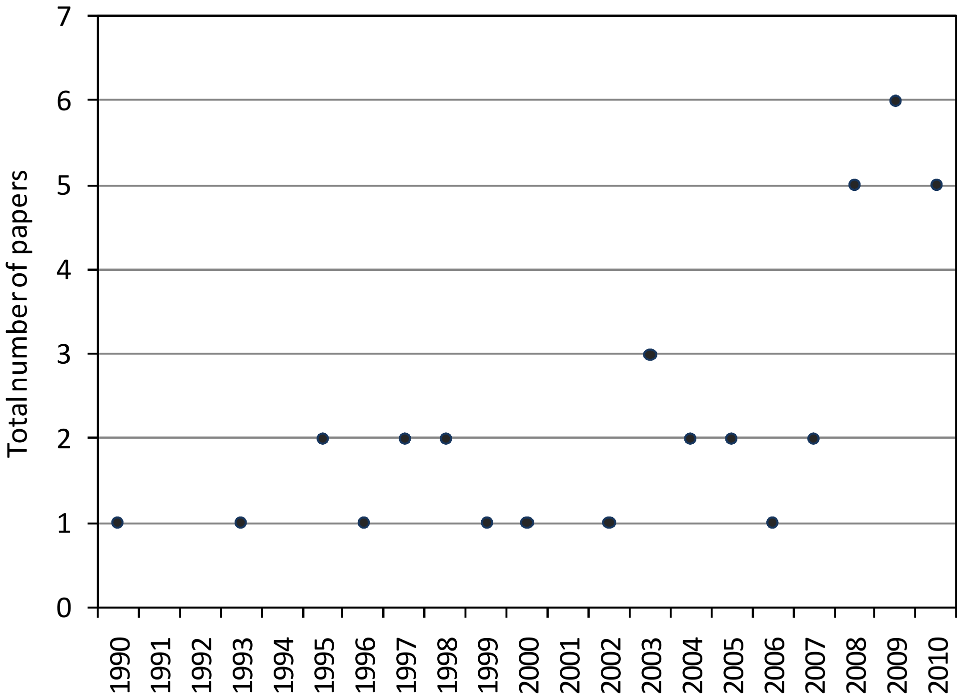
Table 7 shows that the majority (83%) of the sources selected were in peer reviewed scientific journals. Other sources used including conference papers, book chapters, and technical reports accounted for the remainder. There was roughly an equal split in the data sources identified between Africa and South Asia.

Table 7 Number of peer review scientific papers and other sources, aggregated by region.

Data source	Asia only	Africa only	Both Asia and Africa	Total
Peer review scientific paper	21	20	2	43
Other	4	3	2	9
Total	**25**	**23**	**4**	**52**

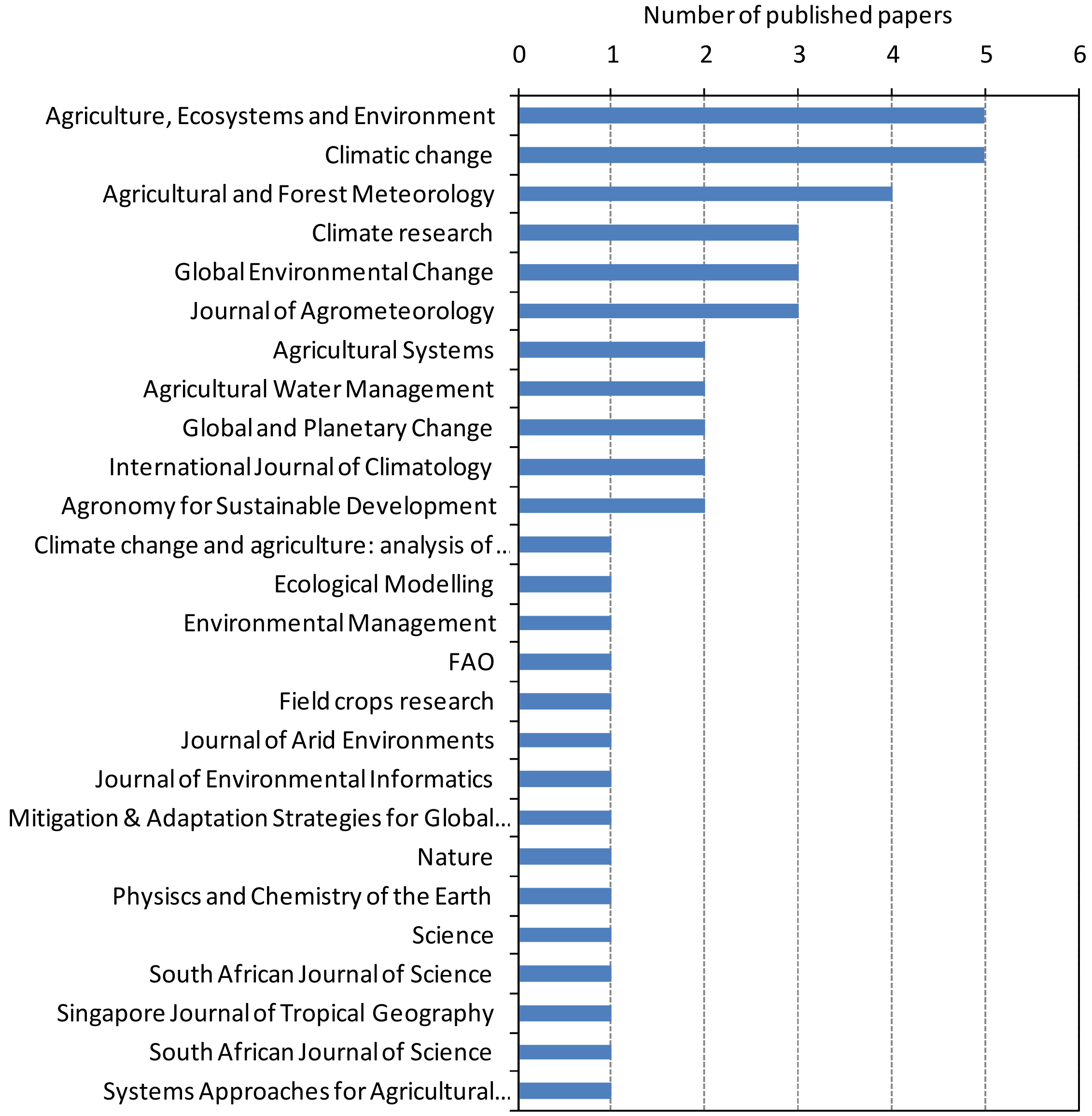
An analysis of the total number of papers used in the review based on their year of publication is summarised in Figure 3. The trend is strongly positive, increasing from two relevant published journal papers from 1990-94 to 19 in the last 5 years.

Figure 3 Summary of papers used in the review, based on number and year of publication.



A summary of the scientific journals from which the papers used in this review were found is shown in Figure 4. The journals 'Agriculture, Ecosystems and Environment', 'Agriculture and Forest Meteorology', 'Climate Research', 'Global Environmental Change' and 'Climatic Change' were the most common, accounting for 19% of the final selection. There were 17 other journals or sources that only contributed one paper each.

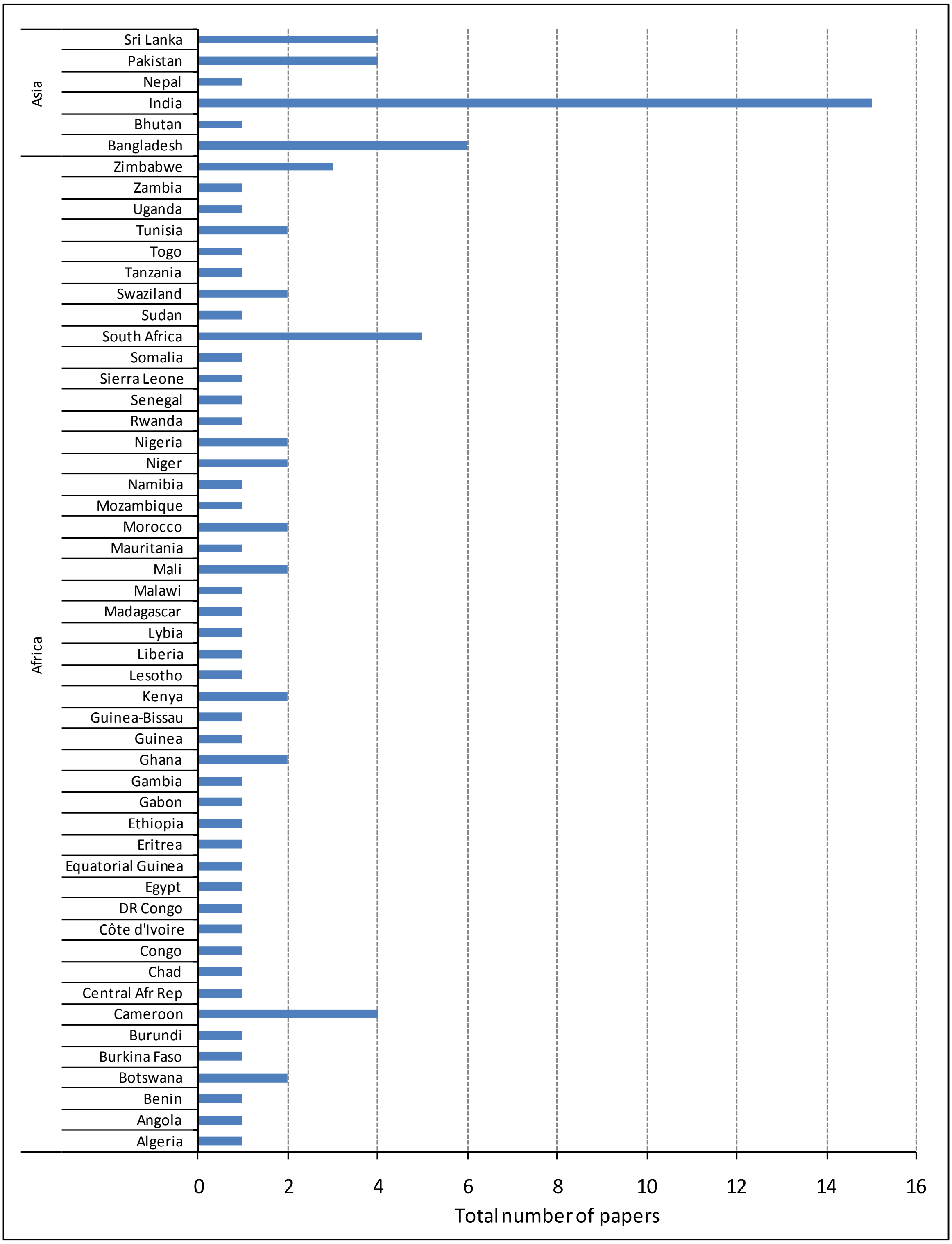
Figure 4 Sources of published papers used in the SR analysis.



Some sources were concerned with a single country; others with multiple countries and some with entire regions. Figure 5 summarises the number of studies that referred to each country and region.

India has been the most widely studied country regarding climate change effects on yield productivity (15 sources) followed by Bangladesh (6 sources) and then South Africa (5 sources).

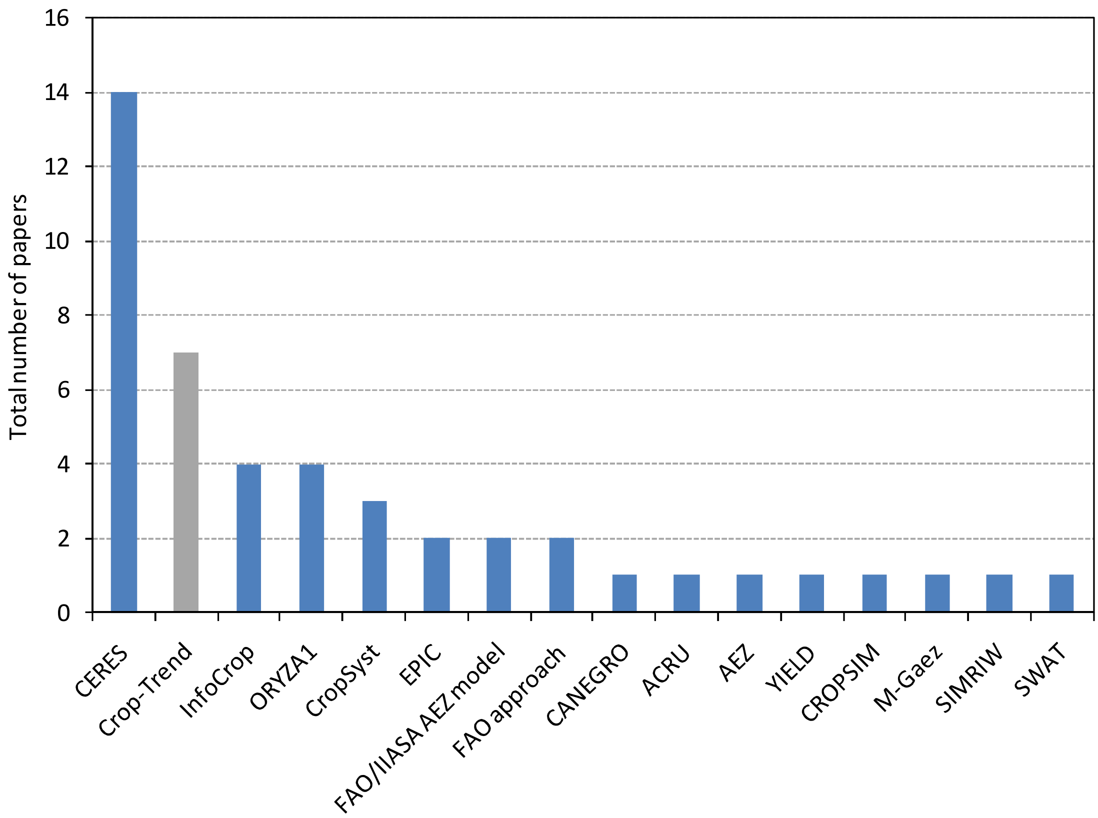
Figure 5 Published peer review papers relevant to the SR, aggregated by region and country.



Many of the earlier climate change impact studies on crop productivity were based on a simple sensitivity analysis, typically adjusting the historical climate (e.g. rainfall and temperature) by fixed amounts (e.g. +10%, +20%, +1°C, +2°C, etc.). In this study, such simple sensitivity analyses are referred to as 'CC-simple' methods; these accounted for 38% of the selected studies. More recently, impact assessments have tended to rely on downscaled outputs from a global circulation model (GCM) or ensemble of GCMs and the outputs then used as the climate input into a crop growth model to simulate future changes in productivity (e.g. Daccache et al., 2010). In this review, these are referred to as 'CC-complex' methods and they accounted for 58% of the studies reviewed. It is important to distinguish between these contrasting methods as they are strong 'effect modifiers' on the observed/reported impacts. The most widely reported crop models used in these 'CC-complex' studies were the CERES suite of models (accounting for 35% of all studies), InfoCrop (4%), Oryza1 (4%) and CropSyst (3%). Other crop models used included EPIC, the FAO/IIASA AEZ model, CANEGRO, ACRU, CROPSIM, SIMRIW and the SWAT model.

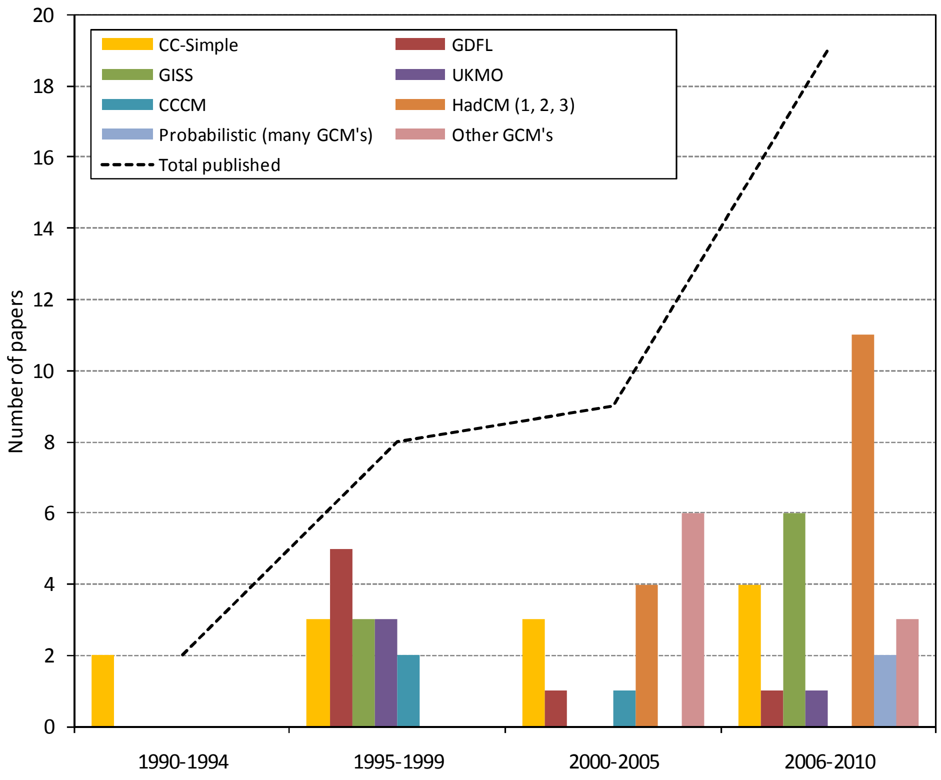
This systematic review also highlighted the different methods being used to model crop productivity. Early studies were predominantly based on an analysis of historical trends in yield and then relating this to past and future climate variability. The alternative, more robust method involves the parameterisation and application of specific biophysical crop growth models to simulate potential changes in crop growth and yield taking into account crop agronomy, land and water management practices. In this study, these two approaches have been defined as 'Crop-trend' and 'Crop-model'. The proportion of studies in this review based on these were 15% and 85%, respectively. The CERES suite of models, including CERES-Maize, CERES-Wheat and CERES-Rice were widely used. Other crop models including InfoCrop, ORYZA1 and CropSyst were also popular (Figure 6). The choice of these models of course strongly reflects the range crop types being cultivated in Africa and S. Asia.

Figure 6 Reported crop modelling approaches (Crop-trend - grey; Crop-model – blue) used in papers relevant to the systematic review.



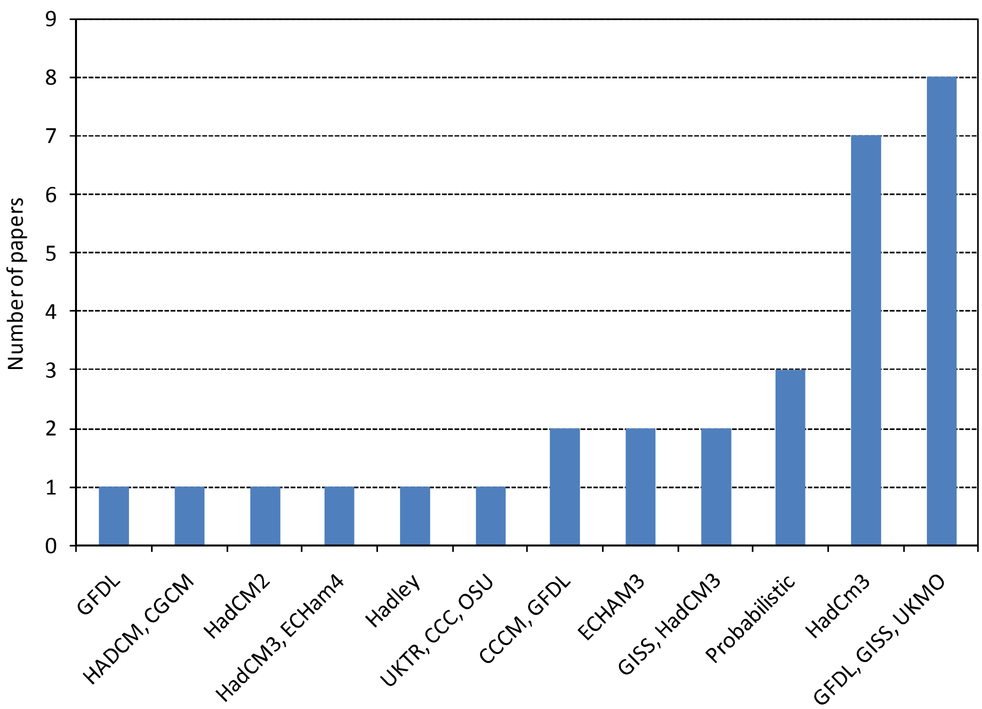
In order to assess whether there was any underlying temporal trend in the climate change methodologies being used, the number of studies using CC-simple and CC-complex approaches since 1990 were assessed (Figure 7). This shows that the number of studies based on CC-complex approaches has increased with time whilst the methods based on applying fixed changes in climate (CC-simple) have remained more or less constant.

Figure 7 Trend in use of 'CC-complex' and 'CC-simple' (blue) methodologies from 1990 to 2010.



The choice of GCM is also a strong effect modifier. Figure 8 summarises the GCMs used in the reported studies. The most widely used GCM was the HadCM usually in combination with GISS. The GFDL, GISS and UKMO GCMs were also commonly used.

Figure 8 Reported GCM models and approaches used in papers relevant to the systematic review.



The research by Mati (2000) studied maize productivity and climate change impacts in five locations in Kenya. Although projected yield responses to climate change were low (<0.5 t ha^{-1}) in all cases the low current yield in some marginal areas (e.g. 0.123 t ha^{-1}) resulted in very large percentage yield increases, which distort the statistical analyses. For that reason, the results of Mati (2000) have been excluded from all analyses.

4.2 Quantitative synthesis overall summary

This section provides a summary of the meta-analyses of projected crop yield classified by crop and by region. Summaries for individual crops are given in Section 4.3.

The following graphs show the analyses of the mean projected yield as a percentage of mean baseline yield from each study ("yield variation"), that is a positive value indicates a projected increase in mean yield whereas a negative value is a projected decrease in mean yield in response to climate change. The projected yields are shown as 'box and whisker' plots where the 'box' defines the upper and lower quartiles. The line shown in the middle of the box represents the median. The 'whiskers' indicate the 10^{th} (lower) and 90^{th} (upper) percentiles. Any outliers below the 10% and above the 90% percentiles are shown as points.

Figure 9 shows a summary of the projected yield variation for all crops and regions by time-slice (i.e. all 256 observations). Overall the median projected yield variation is negative in all time-slices and with smaller decreases projected for the 2020s and 2030s compared to the 2050s and 2080s. However, in all cases the 10% to 90% range spans the zero variation line and some of the studies reviewed projected a large increase in mean yield. The range of projected yield variation is smaller in the 2020s and 2030s. The general trend regarding the values according to time-slice is that the median yield productivity decreases.

Figure 9 Projected yield variation (%) for all crops and regions by time slice.

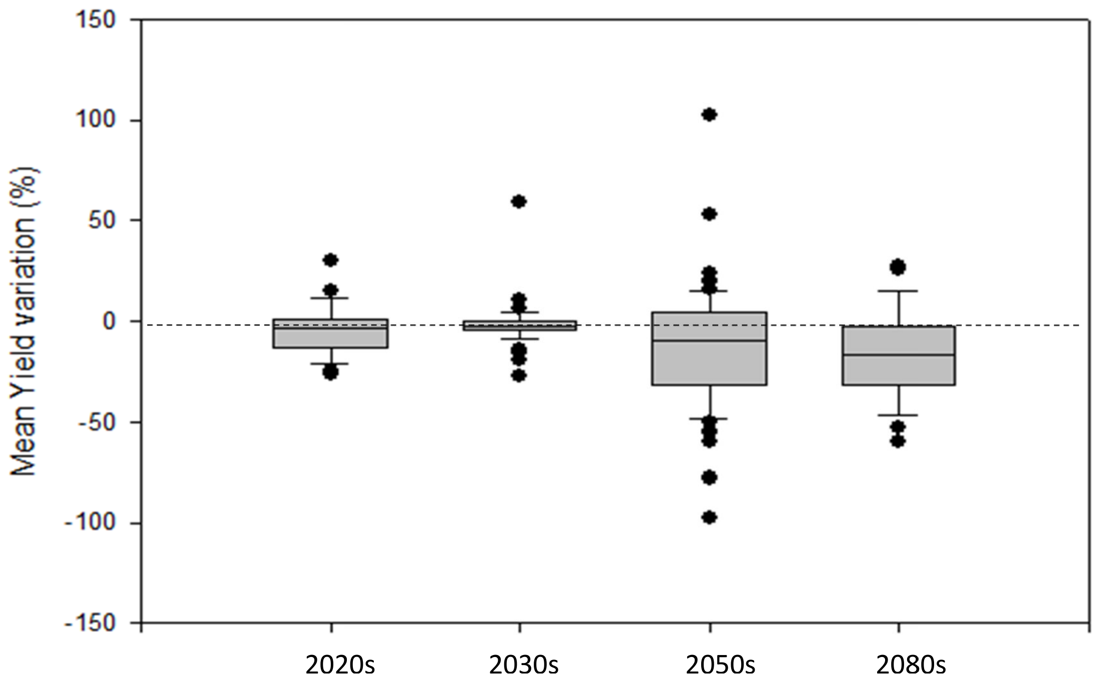


Figure 10 shows a summary of the projected yield variations by region (Africa and S Asia including Bhutan and Bangladesh). For both regions, the median (and interquartile range) of projected variation is negative although in both cases there are several studies that projected an increase in crop yield. For Africa, the range of projected variation is greater than for S. Asia, especially for the outliers.

Figure 10 Projected yield variation (%) for all crops, by region.

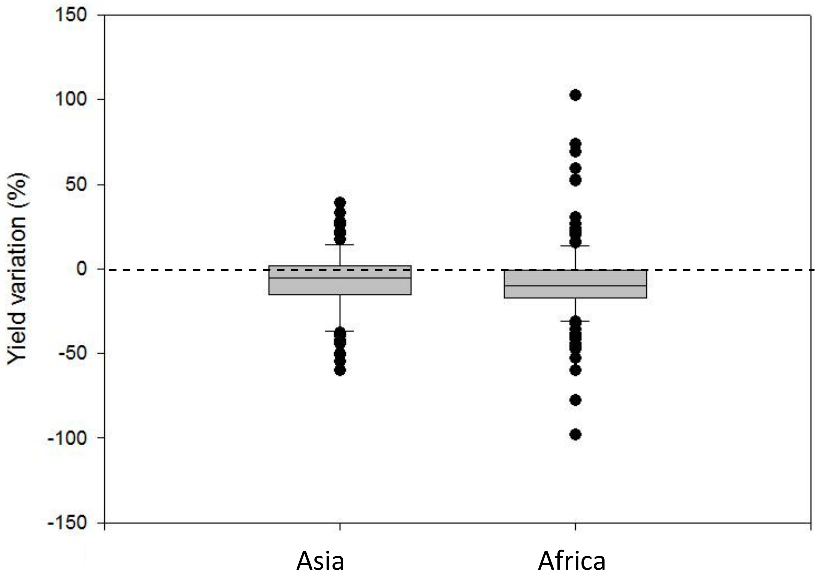


Figure 11 shows the frequency distribution of the yield variation for all the observations given in 10% increments.

Figure 11 Frequency distribution of the yield variation for all the observations

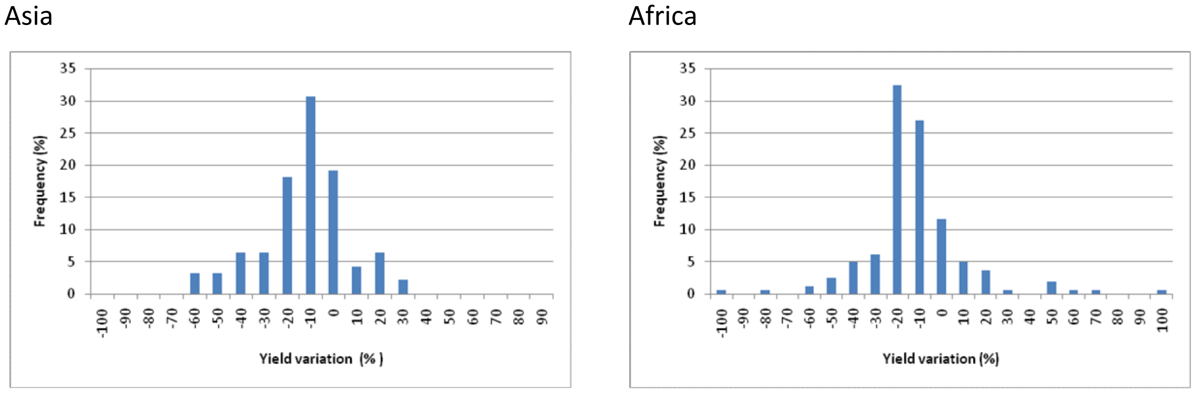


Figure 12 shows a summary of the projected yield variations, by sub-region. Again, most of the sub-regions show a negative median yield variation as a result of climate change. However, the medians for East Africa and the Sahel are both close to the 'no effect' (zero) line; therefore as many projections showed a positive change as a negative one. The regions with the largest proportion of negative values are in Central and West Africa. The highest range in yield variation is for East Africa.

Figure 12 Projected yield variation (%) for all crops, by sub-region. South Asia (including Bhutan and Bangladesh), East, Central, Southern, West, Sahel and Northern Africa.

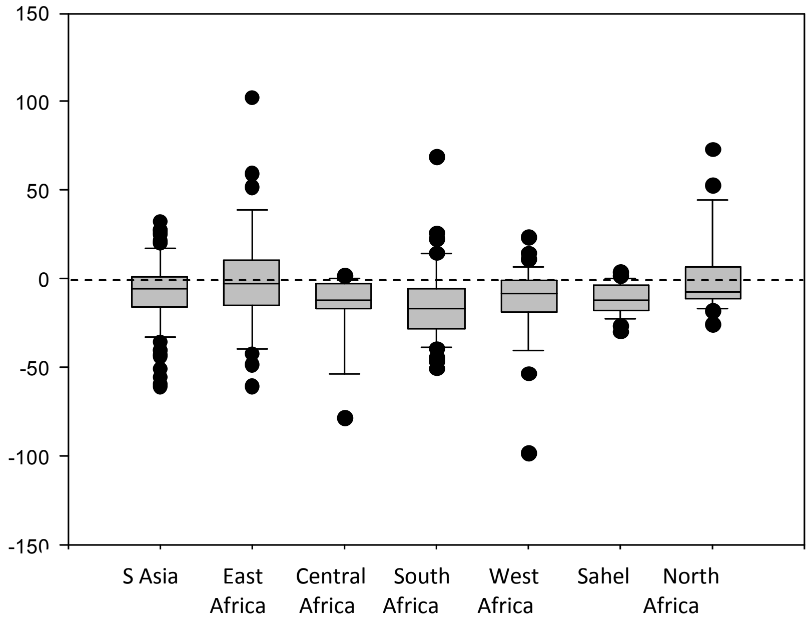


Figure 13 shows a summary of the projected yield variations depending on the climate change modelling approach (i.e. 'CC-simple' or 'CC-complex'). Both medians are below the zero (no change) threshold although the inter-quartile range for the 'CC-Simple' approach spans the zero line. However, the projected variation based on using GCM outputs (CC-complex) show much greater dispersion with many data points located outside the 10th and 90th percentiles.

Figure 13 Projected yield variation (%) for all crops and time slices, aggregated by climate change modelling approach (CC-simple, CC-complex).

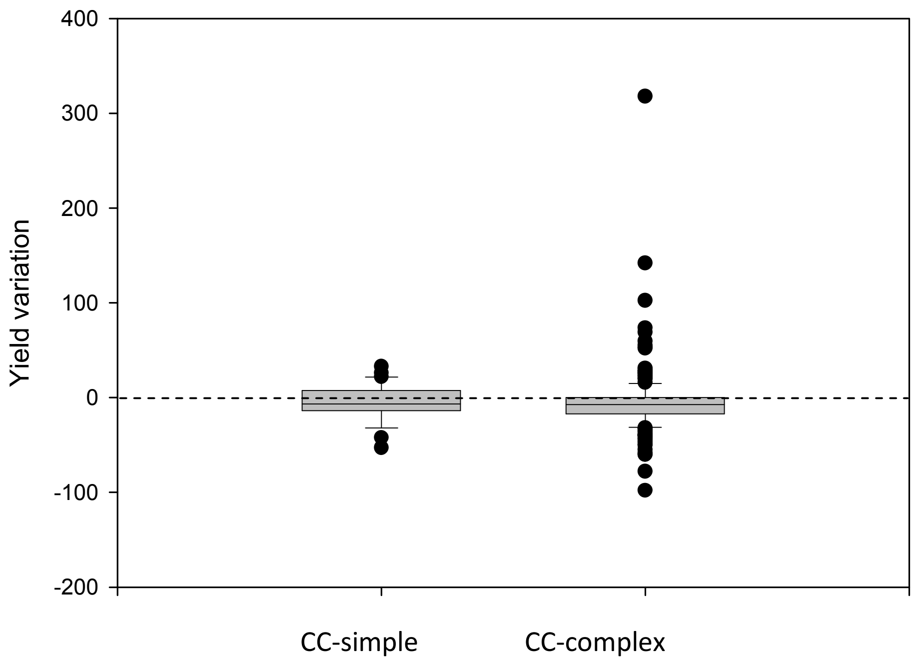


Figure 14 shows the projected yield variation according to the climate change modelling approach. These have been divided into 'Physical' approaches; those based on a single GCM (Single GCM); those based on less than three GCMs (less than 3); and those based on multiple GCMs ('Multiple'). The medians of all four groups are negative, but the variation of the observations is smallest for the projections based on multiple GCMs. However, it should be noted that many of the 'multiple' projections are based on one source, whereas the others are aggregates of multiple sources.

Figure 14 Projected yield variation (%) for all crops and time slices, aggregated by climate change modelling approach (CC-simple, CC-complex).

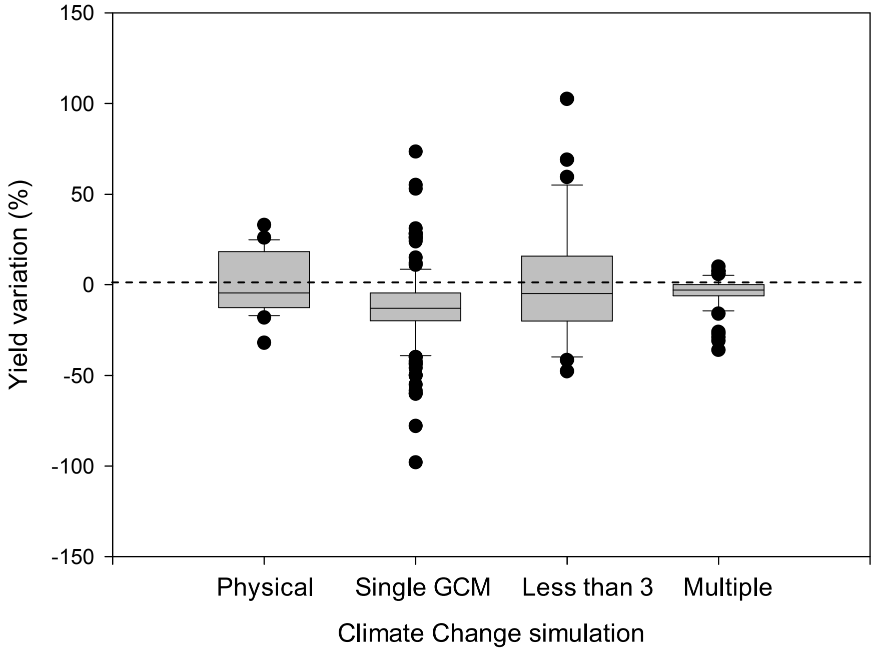
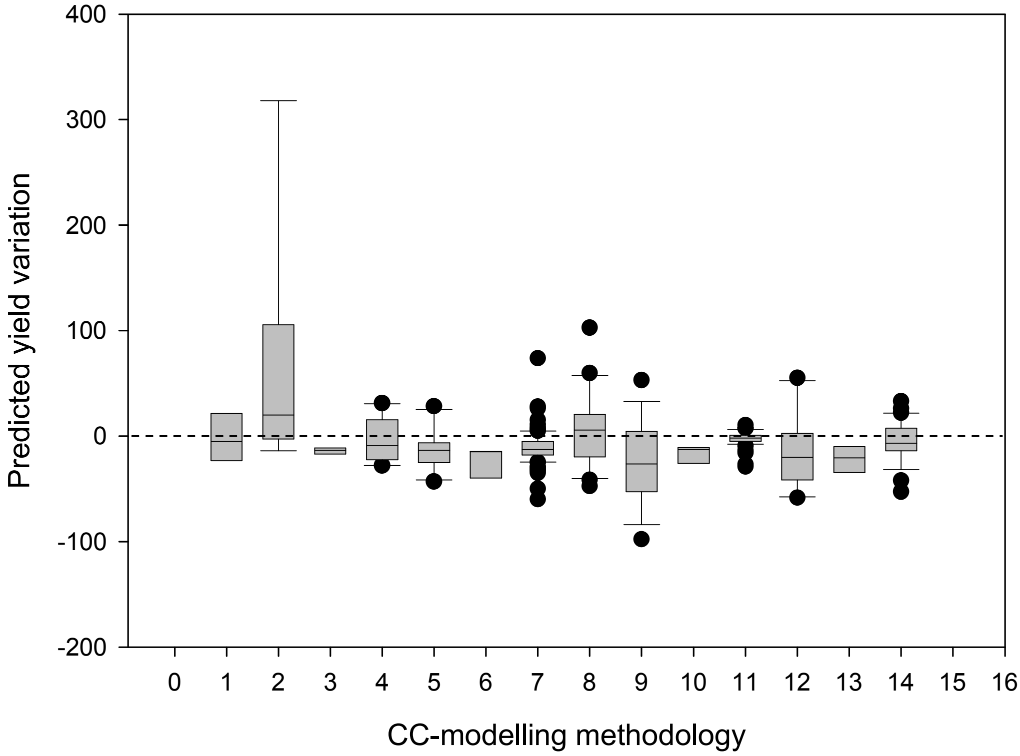


Figure 15 shows a summary of the projected yield variations for studies using various 'CC-complex' methods. From this, it is evident that the projected yield variations derived from using the GCM's CCCM and GFDL, HadCM3 and ECHAM4 all have positive medians. The highest dispersion in the results is for CCCM and GFDL, although most of them are in the lower area. For studies using the CGCM, GISS and HadCM3, MAGICC, HadCM2 and GFDLLO, or UKMO climate models, every projected crop yield impact was negative. The smallest variability within the 10th and 90th percentiles is shown by the values corresponding to CGCM (only 3 values available), followed by the HadCM3 and HADCM GCM models.

Figure 15 Projected yield variation (%) for all observations using the 'CC-complex' methodology.

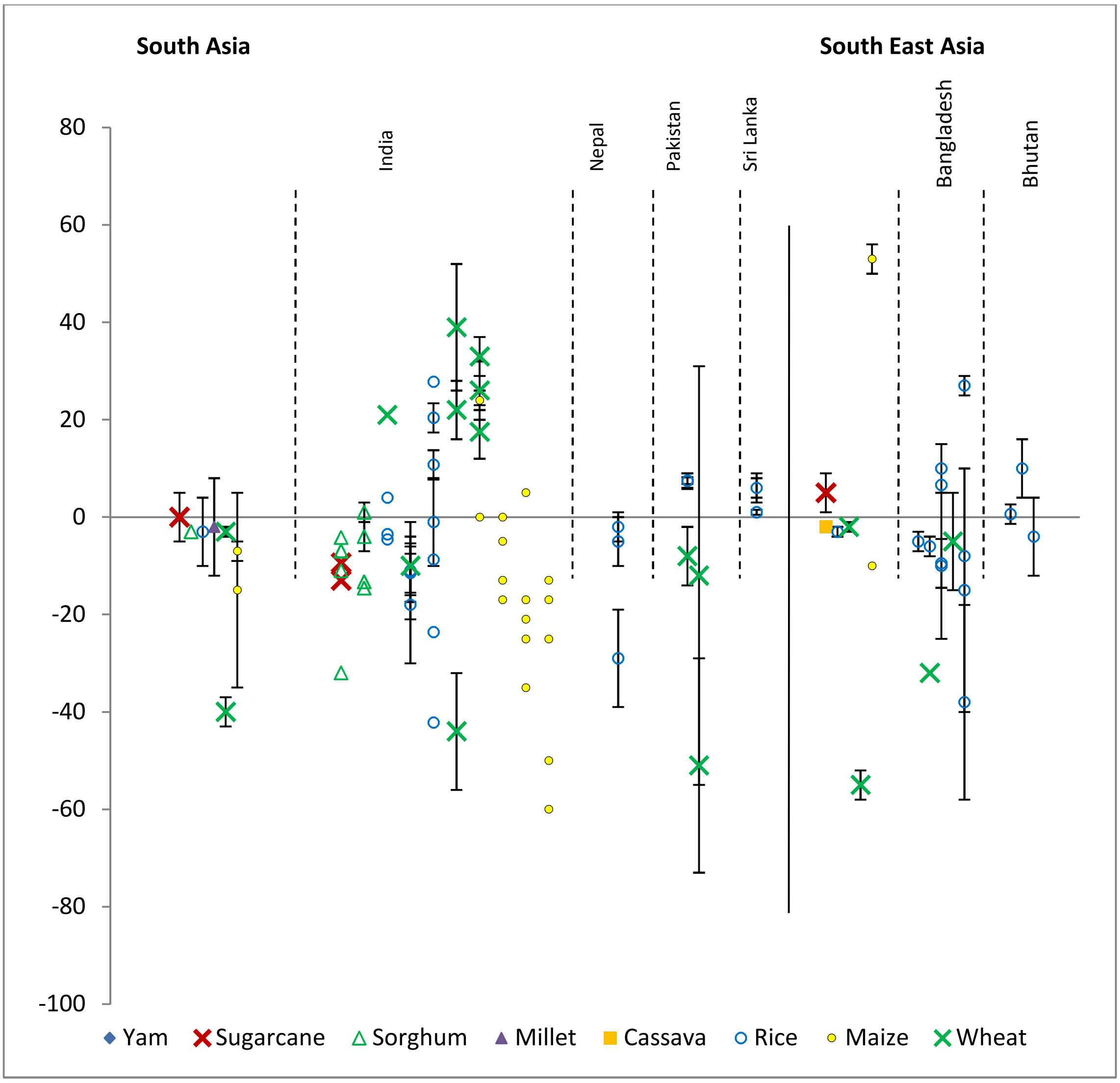


Legend for 'CC-complex' modelling methodologies:

1. ARPEGE Climate
2. CCCM and GFDL
3. CGCM
4. GFDL
5. GISS
6. GISS and HadCM3
7. HadCM3 and HADCM
8. HadCM3 and ECHam4
9. Hadley
10. MAGICC, HAdCM2 and GFDLLO
11. Probabilistic methods (many GCM's and scenarios)
12. UKMO
13. UKTR, CCC and OSU
14. Statistical methods

Figure 16 and Figure 17 show the projected yield variations for all observations (all crops and time slices) in S Asia and Africa, respectively.

Figure 16 Predicted yield variations (% change) for all observations in S Asia.



In Figure 18, the observations have been aggregated for both Africa and S. Asia, and the crop types grouped according to whether they are C3 or C4 plant species.

Figure 17 Summary of reported yield variations (%) for all observations in Africa.

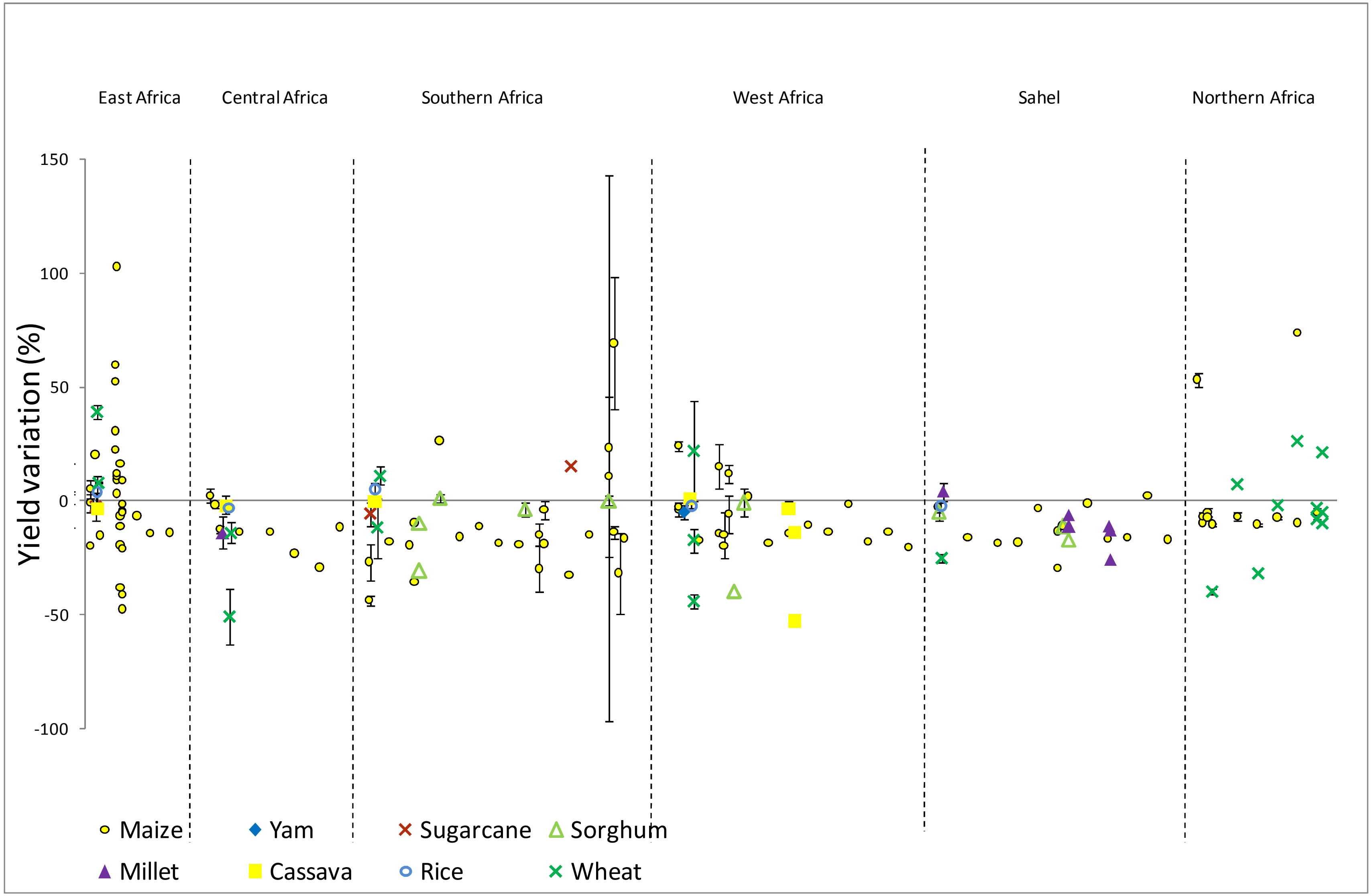


Figure 18 Summary of reported yield variations (%) for all C4 (yellow) and C3 (green) crops and all time slices in Asia and Africa.

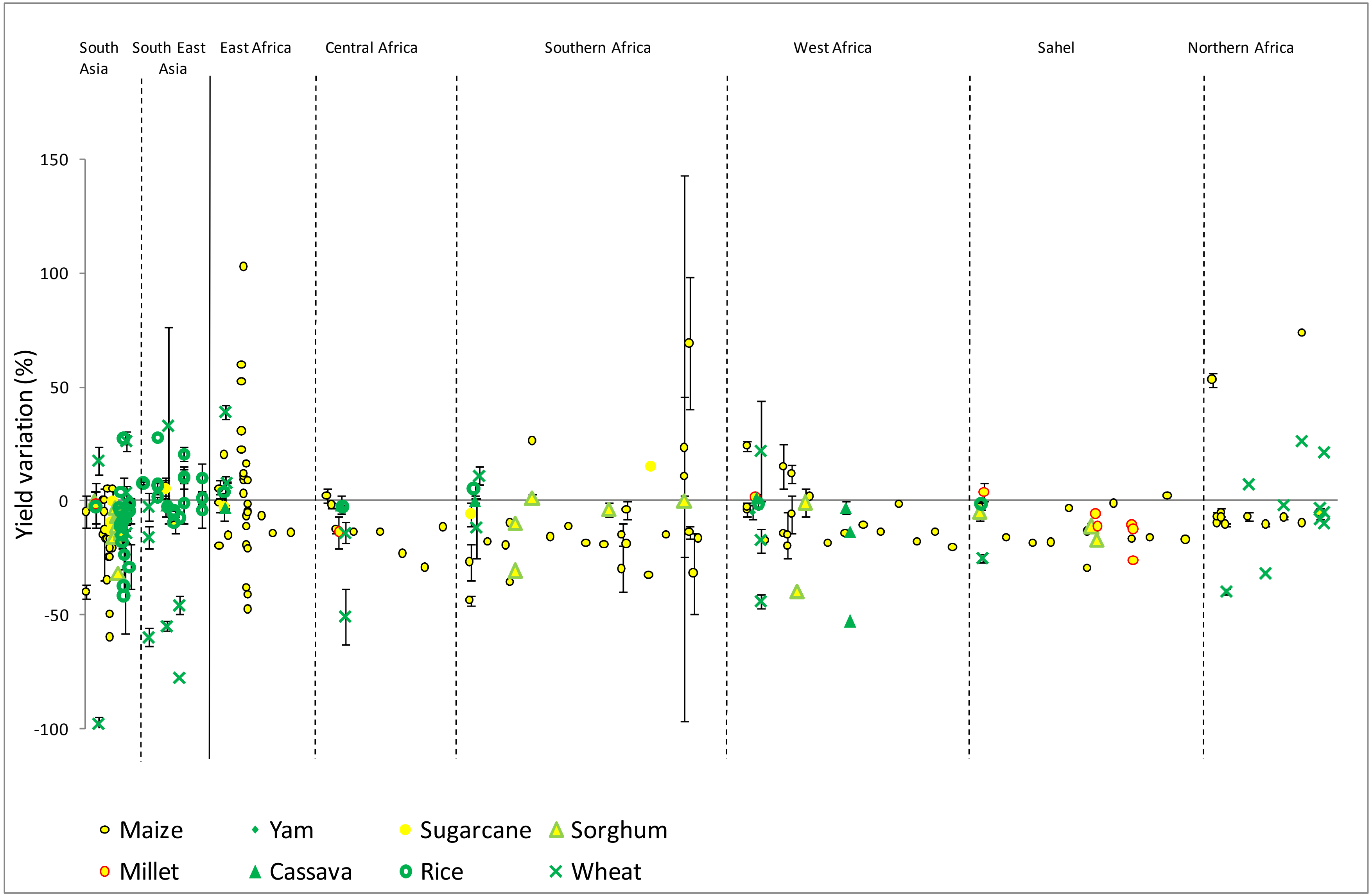


Figure 19 and Figure 20 summarise the positive and negative reported yield variation by sub-region for all C3 and C4 crops. The C3 crops include wheat, rice, cassava and yam; the C4 crops include maize, sugarcane, sorghum and millet. Table 8 summarises the data presented in these graphs.

From these figures, it is apparent that the general trend in yield variation is negative for C4 crops with the exception of East Africa, where the split between positive and negative impacts are similar. The impacts on C3 crops are also mostly negative, but to a lesser extent.

Figure 19 Number of positive and negative reported yield changes for all C3 and C4 crops, aggregated by sub-region.

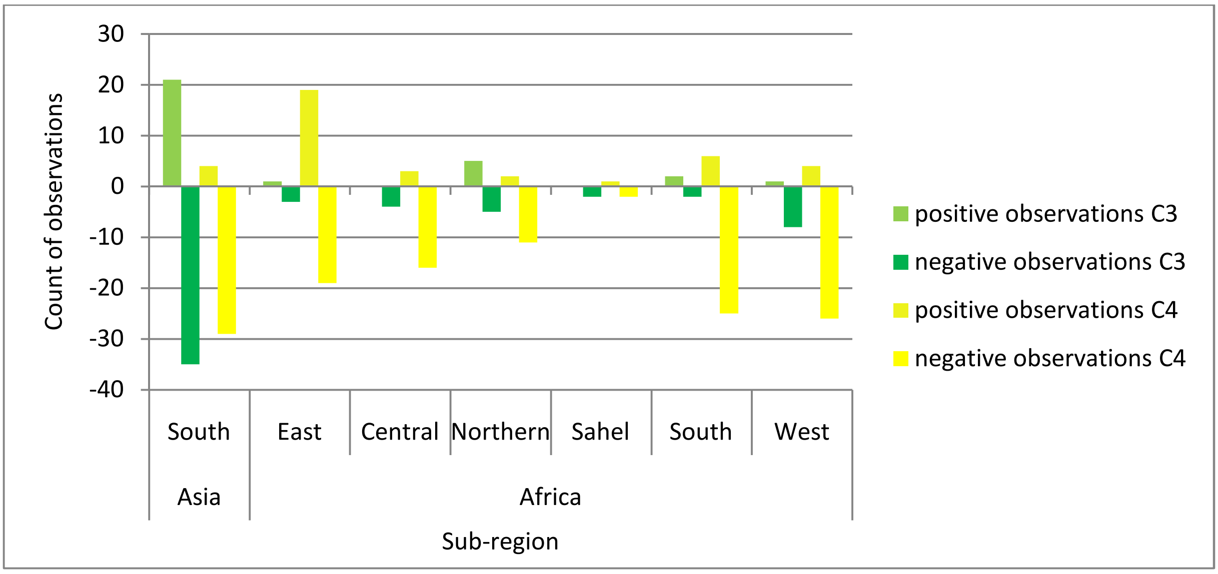


Figure 20 Proportion of studies (%) reporting positive and negative yield changes for C3 and C4 crops, aggregated by sub-region.

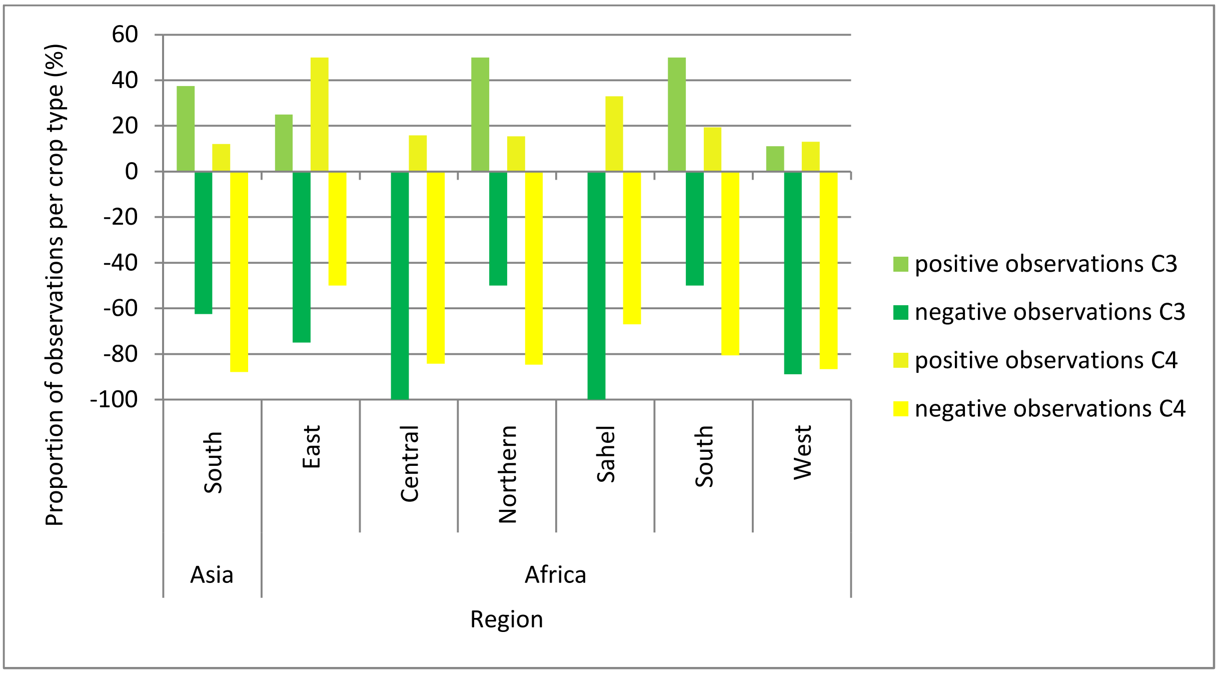


Table 8 Number of reported observations showing positive and negative yield variations, aggregated by region and by crop type (C3 or C4).

Crop	Asia	Africa						Total
		East	Central	Northern	Sahel	South	West	
Positive C3	21	1	0	5	0	2	1	30
Negative C3	35	3	4	5	2	2	8	59
Positive C4	2	19	3	2	1	6	4	39
Negative C4	29	19	16	11	2	25	6	128

4.3 Quantitative synthesis by crop type

The following sections provide a synthesis of the projected yield variations due to climate change by crop type, for each region. The figures show the mean projected yield variation and, where reported, the range as error bars.

For each crop, five sets of analyses are presented. Firstly, for all observations (i), then by time-slice (ii), then by 'CC-simple' and 'CC-complex' methodologies (iii), then by CC-complex only (iv) and finally by 'CC-simple' only. This helps to identify the impact of the various climate change modelling and the crop modelling approach on the results and hence the likely impact of these effect modifiers on the overall trends.

4.3.1 Rice

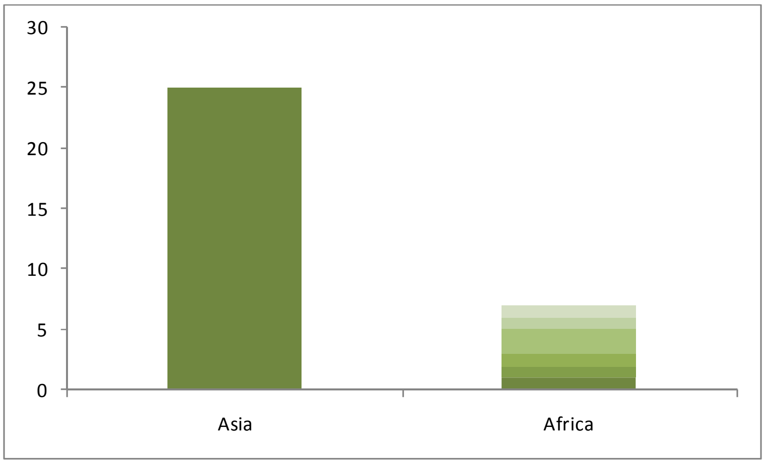
4.3.1.1 Data sources

The review identified 25 sources relating to climate change impacts on rice productivity in Asia (Table 9). 19 of these were in peer reviewed journals; the majority (16) of which were published in 12 journals whilst the others were technical/conference papers (Palanisami et al., 2008; Mohandass and Ranganathan, 1997) and a book chapter (Modandass et al., 1997). A further 6 'other' sources of data were also used.

Table 9 Summary of peer review papers included in the review for rice in Asia.

Author and year	Country/region	Journal
ASIA		
De Costa et al. (2006)	Sri Lanka	Field Crops Research
Devries (1993)	India	Systems Approaches for Agricultural Development
Droogers (2004)	Sri Lanka	Agricultural Water Management
De Silva et al. (2007)	Sri Lanka	Agricultural Water Management
Faisal and Parveen (2004)	Bangladesh	Environmental Management
Geethalaksmi et al (2008)	India	Journal of Agrometeorology
Das et al. (2007)	Bangladesh	Journal of Agrometeorology
Masutomi et al (2009)	Pakistan, Bangladesh, Sri Lanka, Nepal, Bhutan	Agriculture, Ecosystems and Environment
Krishnan et al (2007)	India	Agriculture, Ecosystems and Environment
Lobell (2007)	India	Agricultural and Forest Meteorology
Lal et al. (1998)	India	Agricultural and Forest Meteorology
Lobell et al. (2008)	Global	Science
Mahmood (1998)	Bangladesh	Ecological Modelling
Matthews et al. (1997)	India, Bangladesh	Agricultural Systems
Saseendran et al. (2000)	India	Climatic Change
Swain and Yavad (2009)	India	Journal of Environmental Informatics
AFRICA		
Lobell et al. (2008)	Global	Science
Odingo (1990)	Regional	Book chapter
Adejuwon (2005)	Nigeria	Singapore Journal of Tropical Geography

Figure 21. Number of published data sources used assessing climate change impacts on rice in Africa and Asia



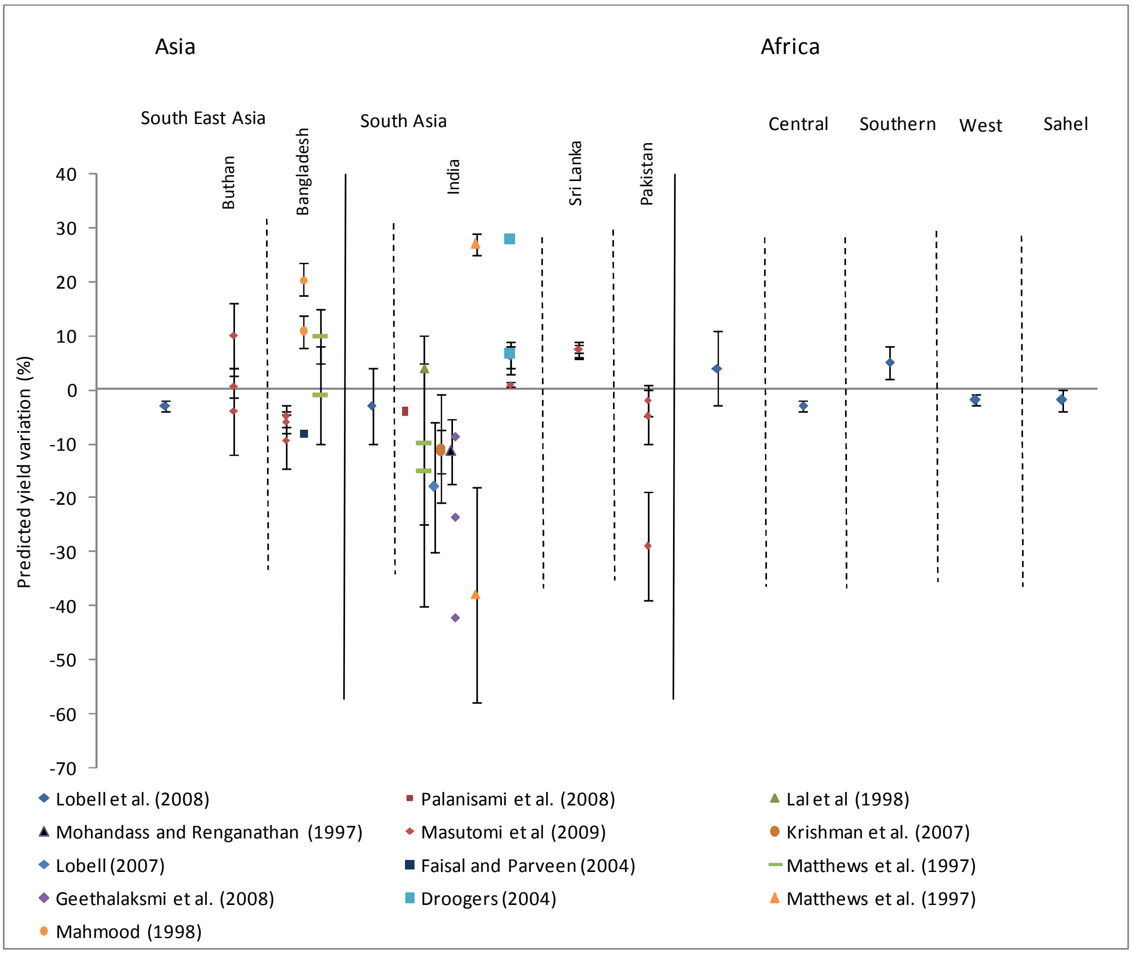
Only 3 sources were identified for rice production in Africa. Two of these were published in peer reviewed journals whilst the third is a book chapter (Odingo, 1990). In addition, Leemans and Solomon (1993) published a study regarding climate change effects on several crops in Africa and Asia in Climate Research.

Some of the studies focused on a specific country or region (e.g. Adejuwon, 2005, in Nigeria; Saseendran et al., 2000, Mohandass and Ranganathan, 1997, Geethalaksmi et al., 2008, and Krishnan et al., 2007, in India; Faisal and Parveen, 2004, Mahmood, 1998, and Das et al., 2007, in Bangladesh; and Droogers, 2004, in Sri Lanka) whilst others studied much larger geographical areas and provided results for different countries (Masutomi et al., 2009, and Matthews et al., 1997) or regions (Lobell et al., 2008). The results from Adejuwon (2005) are not included in the following analyses, because their data were not in a comparable format to those presented by other authors.

4.3.1.2 Overall results

Figure 22 summarises the results for all observations relating to rice in Africa and S Asia. This contains the results corresponding to different time slices (2020s, 2030s, 2050s and 2080s), GCMs (GISS, GFDL, UKMO) with no specified prediction period, other possible future scenarios (e.g. temperature increase by 2^{o}C), and studies based on variation in the average temperature and diurnal temperature range.

Figure 22 Reported variations in rice yield (%) for all observations.

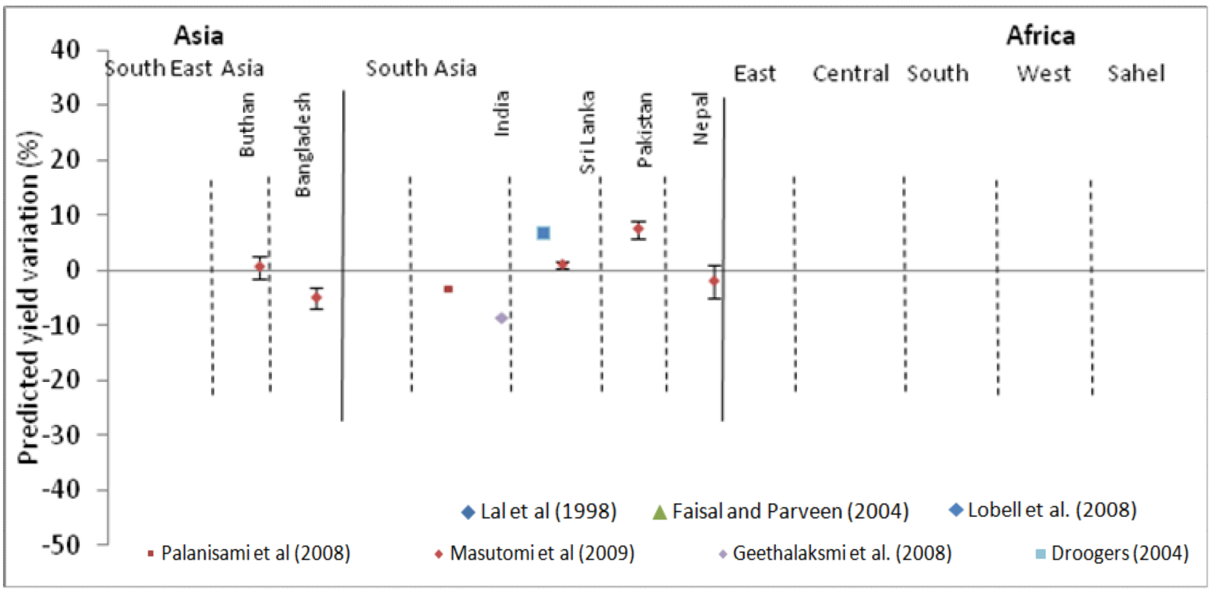


4.3.1.3 Results by time slice

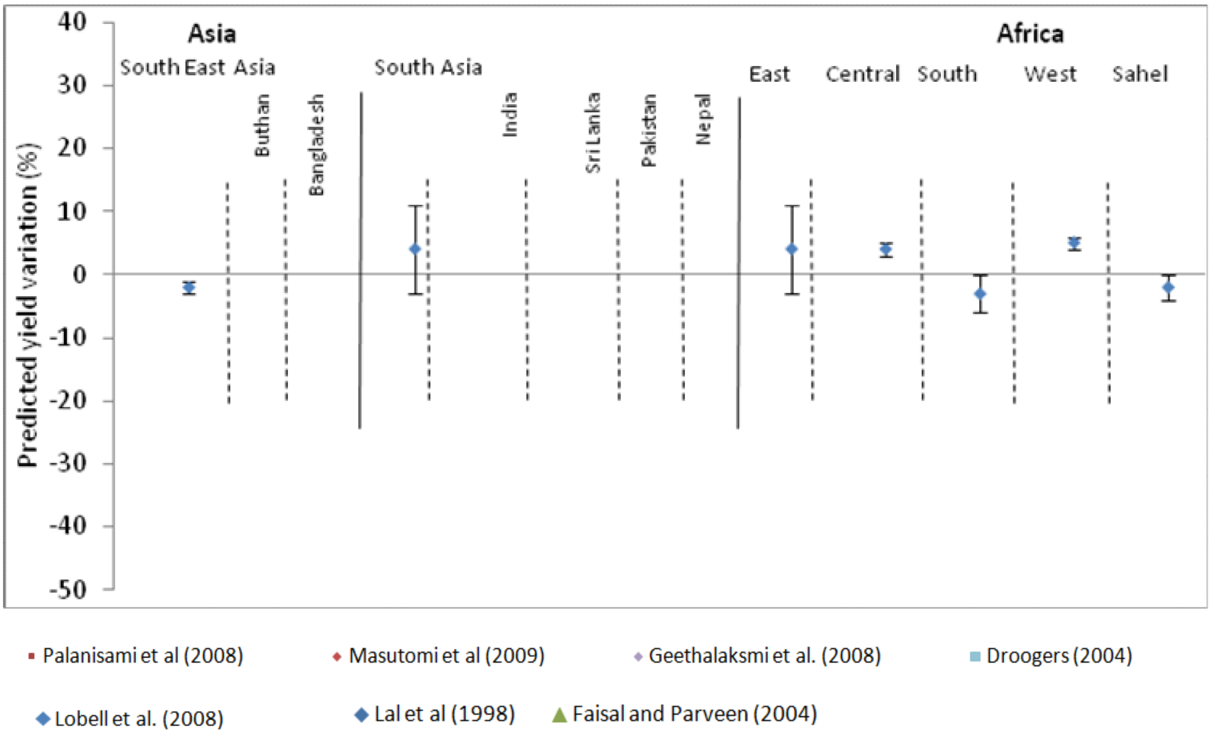
Figure 23 shows the projected impact on yield variation by time-slice. There were no impacts reported for rice in Africa for the 2020s, 2050s and 2080s.

Figure 23 Reported variations in rice yield (%) for four time-slices.

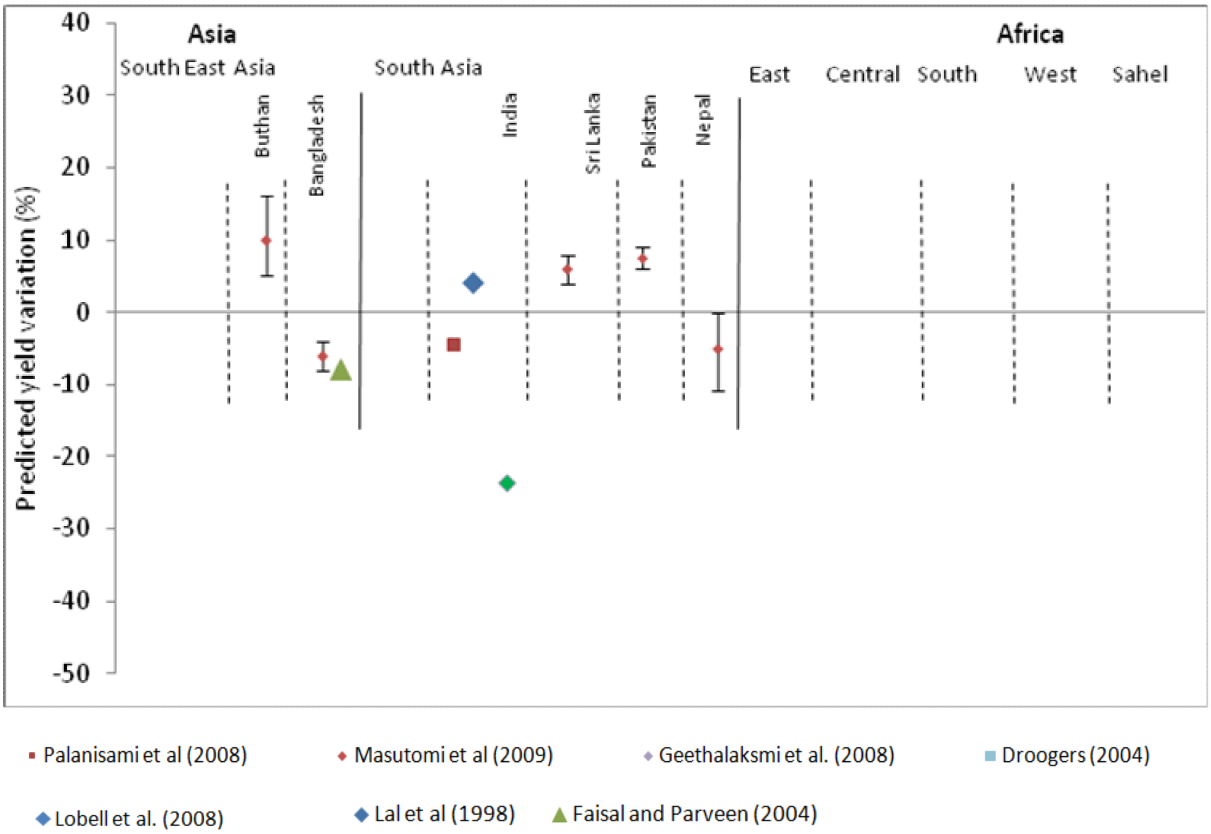
(a) 2020s



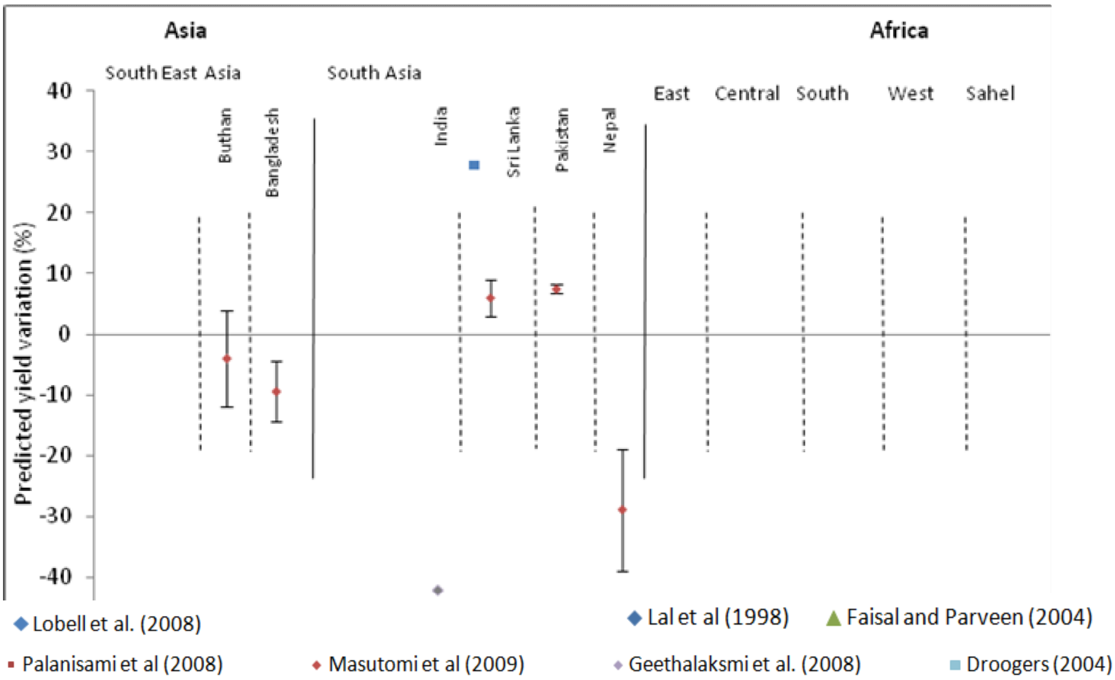
(b) 2030s



(c) 2050s



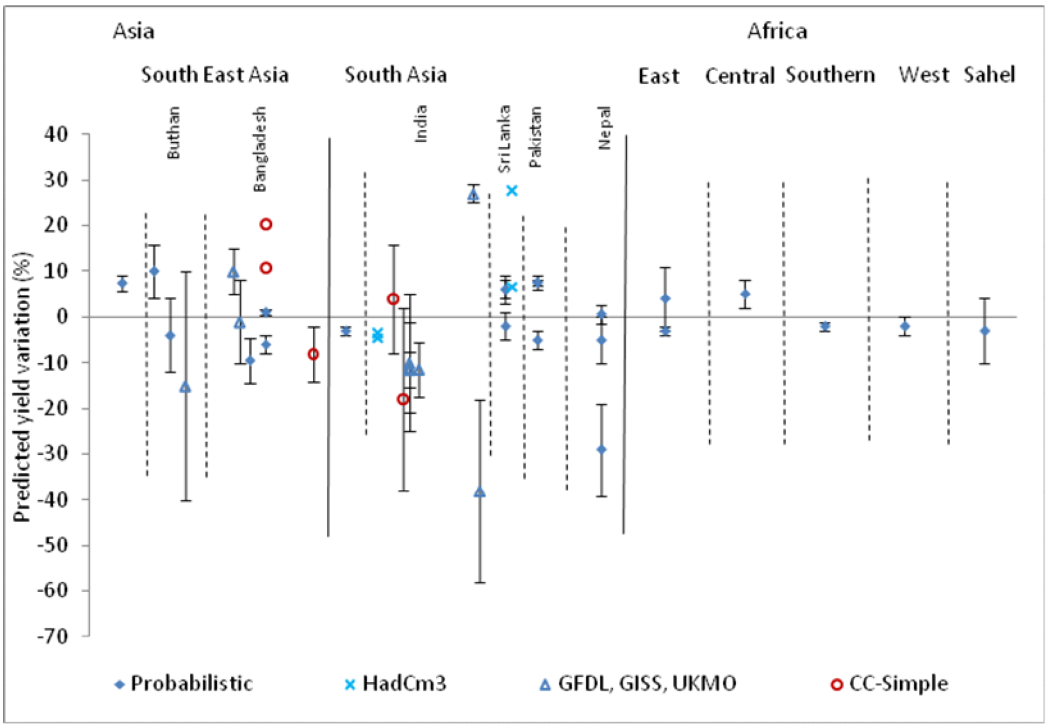
(d) 2080s



4.3.1.4 Results by climate change methodology (CC-simple and CC-complex)

Figure 24 shows the projected impact on rice yield variation using different approaches to climate change modelling (CC-simple and CC-complex).

Figure 24 Reported variations (%) in rice yield in S. Asia and Africa, for both CC-simple and CC-complex) climate change modelling methods.



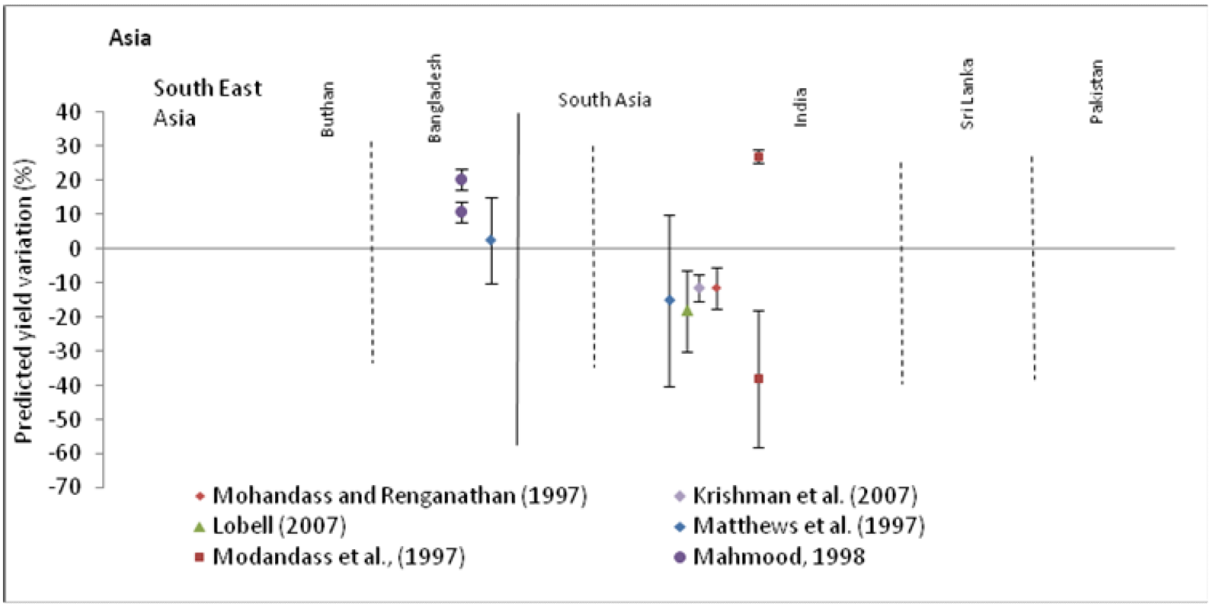
4.3.1.5 Results based on CC-simple methodologies

No data available

4.3.1.6 Results by CC-complex methodologies

Figure 25 shows the results for simulations carried out using CC-complex methodologies i.e. using the GCM's GISS, GFDL and UKMO (Mohandass and Reganathan, 1997; Krishman, 2007; Matthews et al., 1997; Mohandass et al., 1997), for an increase in temperature of 2^{o}C (Mahmood, 1998) and an increase in average temperature and diurnal temperature range (Lobell 2007). Mohandass et al., (1997) show the results for the predictions in rice yield variation in the main season (+27%) and the secondary season (-38%).

Figure 25 Reported impacts on rice yield for the CC-complex methodologies.



4.3.2 Wheat

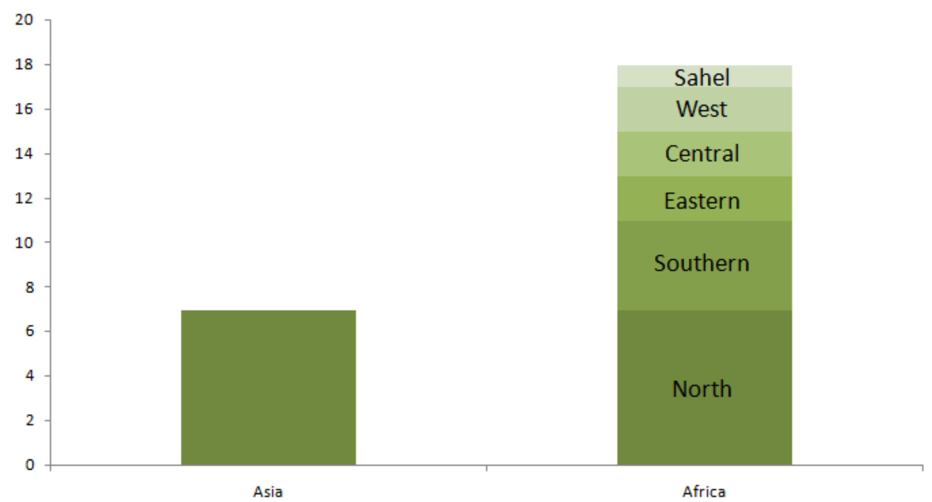
4.3.2.1 Data sources

The review identified 8 relevant sources relating to climate change impacts on wheat productivity in Asia and 7 studies for Africa (5 journals, a conference publication and a book chapter) (Table 10). A summary by region is given in Figure 26.

Table 10 Summary of literature included in the review for wheat in Asia and Africa.

Author and year	Country/region	Journal title/report
ASIA		
Faisal and Parveen (2004)	Bangladesh	Environmental Management
Fischer (2009)	Global	Expert meeting on How to Feed the World in 2050, FAO
Fischer et al. (1996)	India, Pakistan	FAO paper
Lobell (2007)	India, Pakistan	Agricultural and Forest Meteorology
Lal et al. (1998)	India	Agricultural and Forest Meteorology
Lobell et al. (2008)	Global	Science
Suitana et al (2009)	Pakistan	International Journal of Climatology
Attri and Rathore (2003)	India	International Journal of Climatology
AFRICA		
Blignaut et al. (2009)	South Africa	South African Journal of Science
Fischer (2009)	Global	Expert meeting on How to Feed the World in 2050, FAO
Giannakopoulos et al. (2009)	Morocco, Algeria, Tunisia, Libya, Egypt	Global and Planetary Change
Gbetibouo and Hassan (2005)	South Africa	Global and Planetary Change
Lhomme et al. (2009)	Tunisia	Climatic Change
Lobell et al. (2008)	Global	Science
Odingo (1990)	Continental	Soils on a warmer Earth

Figure 26 Number of published data sources used for assessing climate change impacts on wheat in Africa and Asia.

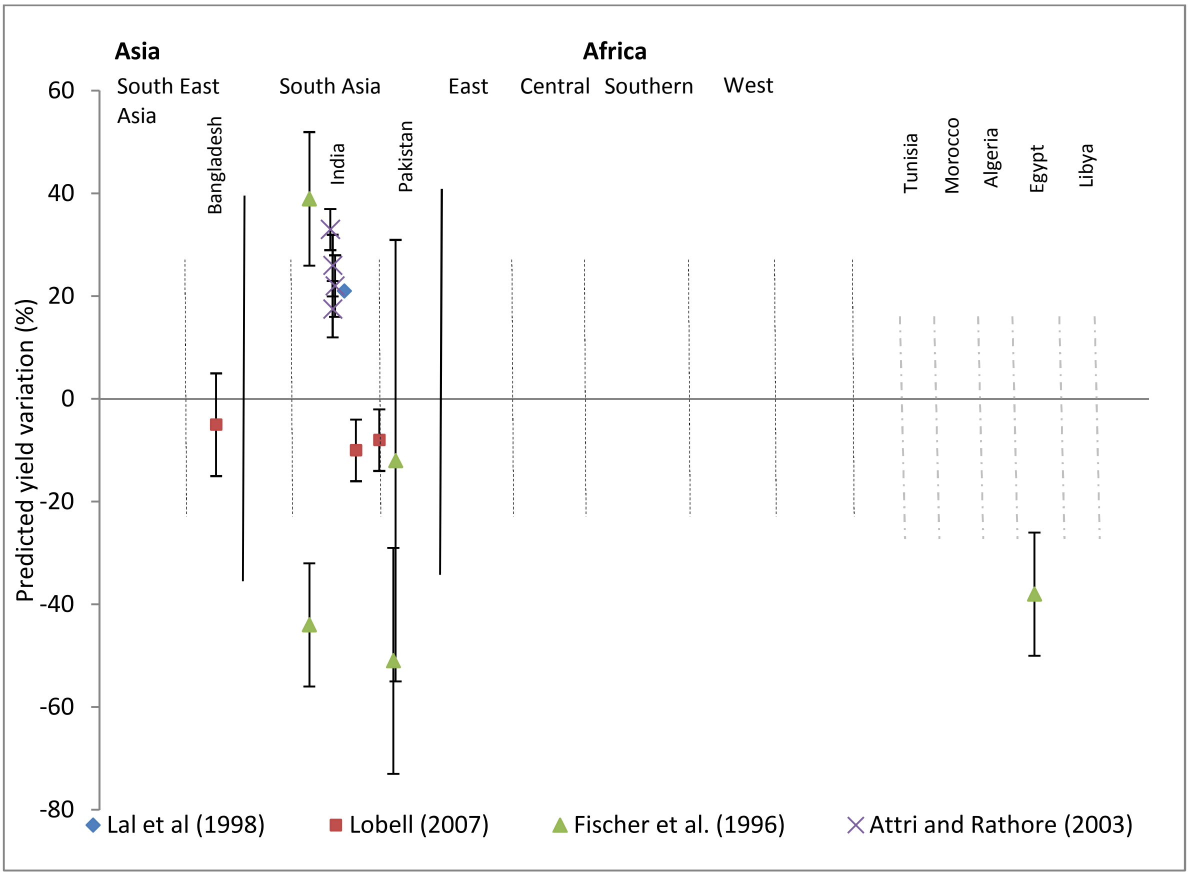


4.3.2.2 Overall results

Figure 27 shows the published results regarding the projected variation in future wheat productivity in Asia and Africa, by sub-region. The general overall trend is negative. This data contains results corresponding to different time slices (2030s, 2050s and 2080s), emissions scenarios (Fischer et al., 1996), and studies based on variations in average temperature and diurnal temperature range (Lobell, 2007).

The yield variations were obtained using different climate scenarios (Lal et al., 1998; Attri and Rathore, 2003), different GCM's (Fischer et al., 1996) and studies based on increasing temperature and diurnal temperature range. Attri and Rathore (2003) estimated yield variation for two different climatic scenarios and under irrigation and rain-fed conditions showing four different results.

Figure 27 Reported variation in wheat yield (%) with climate change for all observations.



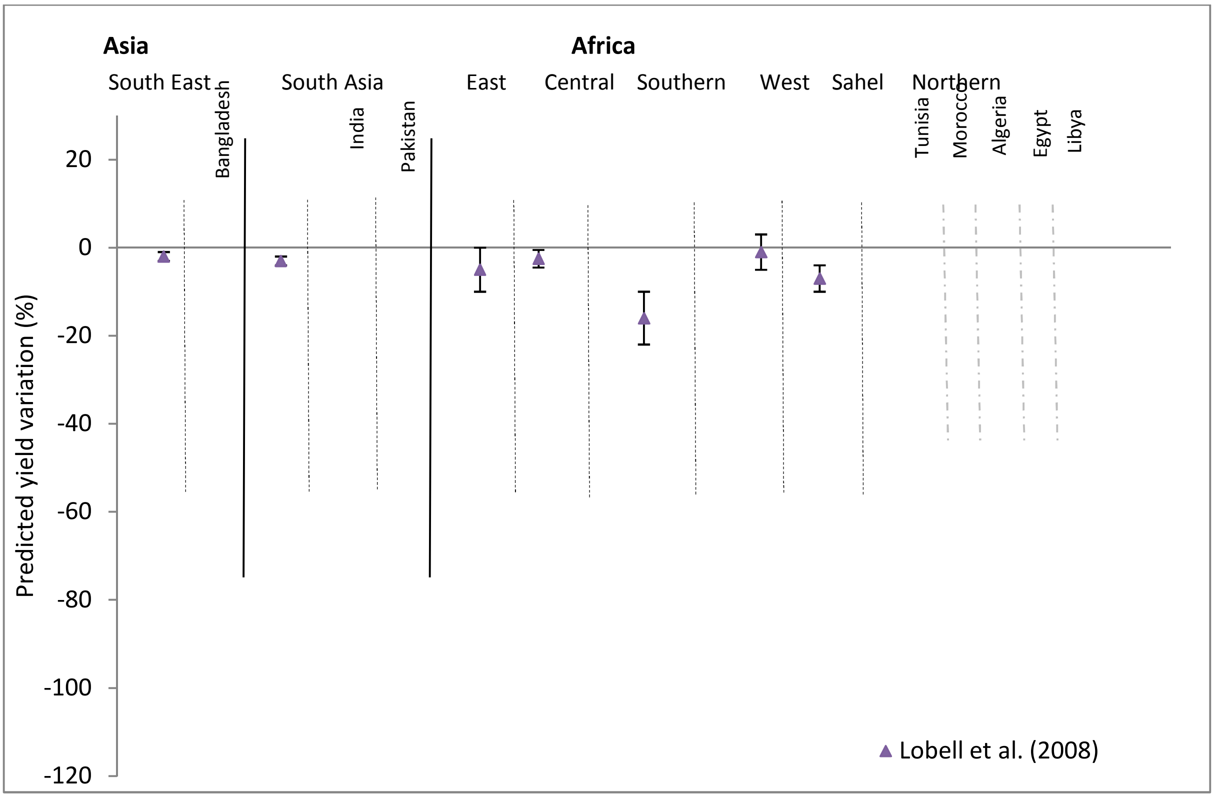
4.3.2.3 Results by time slice

Figure 28 shows the projected impact on wheat yield variation by time-slice. The predictions are all negative. For the 2050s, the results from Giannakopoulos et al. (2009) show a predicted negative impact on yield for all regions, except for Northern Africa, where a small increase is predicted for wheat production in Tunisia, Algeria and Libya.

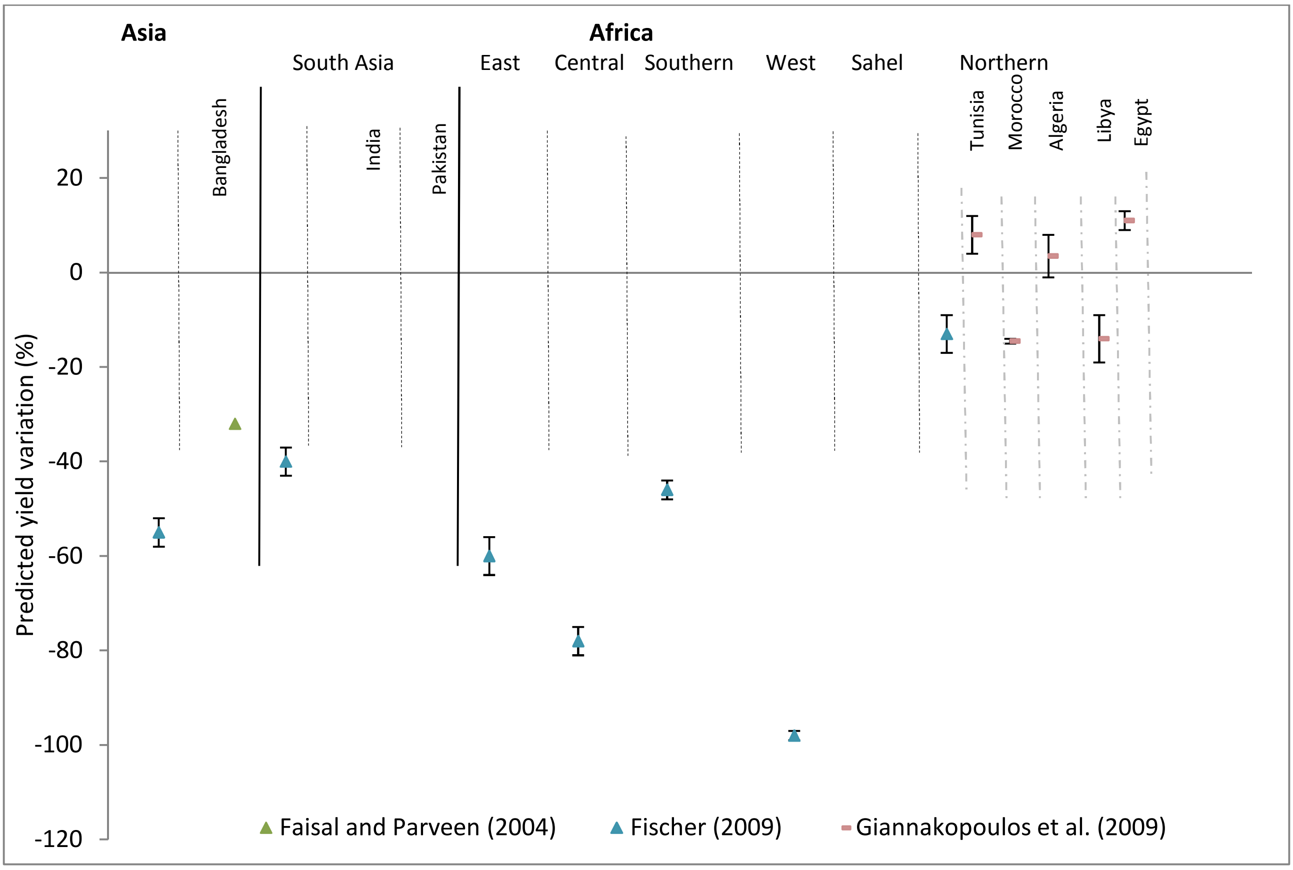
The yield variation predicted for the 2080s based on Lhomme et al. (2009) is for two different locations in Tunisia (Kairouan and Jendouba) and for two planting conditions. In Kaironan the yield is projected to increase in both cases. In the case of "not prescribed sowing date" (1) the increase would be of 26.2% and 6.8% at "Prescribed sowing date and supplemental irrigation" (2). In Jendouba, climate change would have a negative impact under both conditions, namely -17.6% (1) and -25.3% (2), respectively.

Figure 28 Reported variations (%) in wheat yield in S. Asia and Africa by time slice.

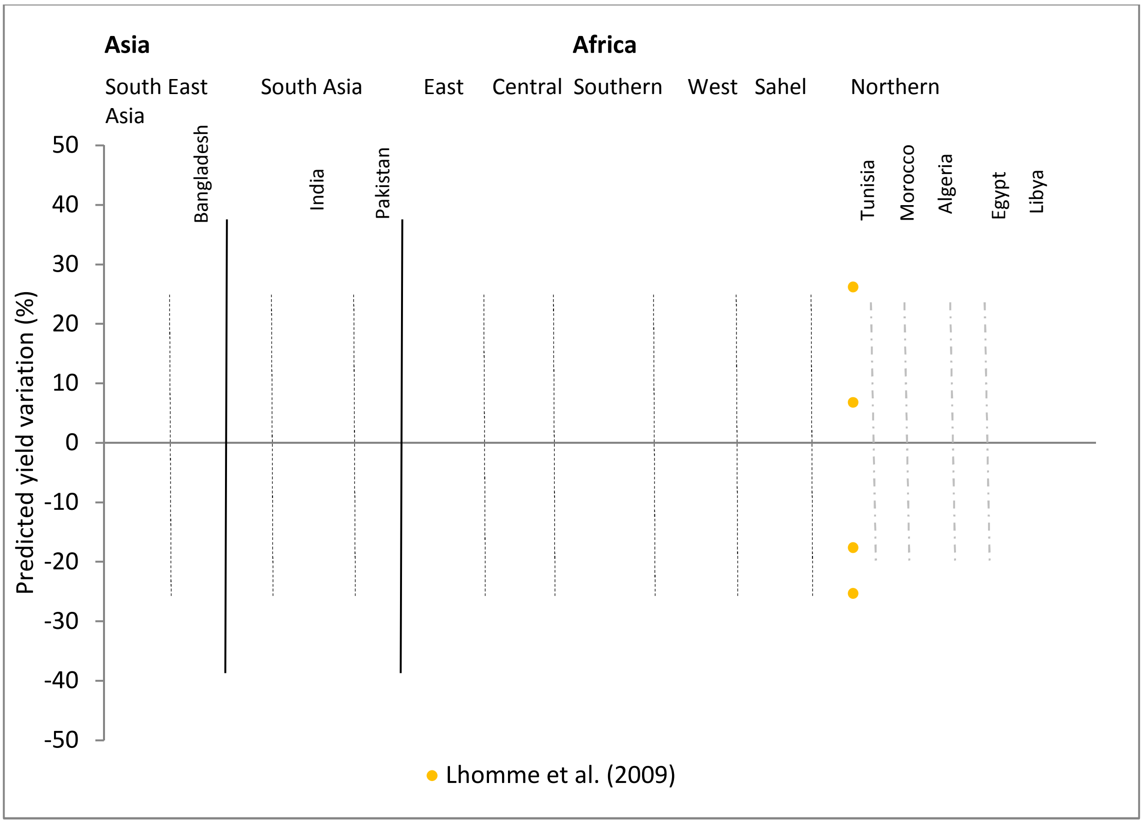
(a) 2030s



(b) 2050s



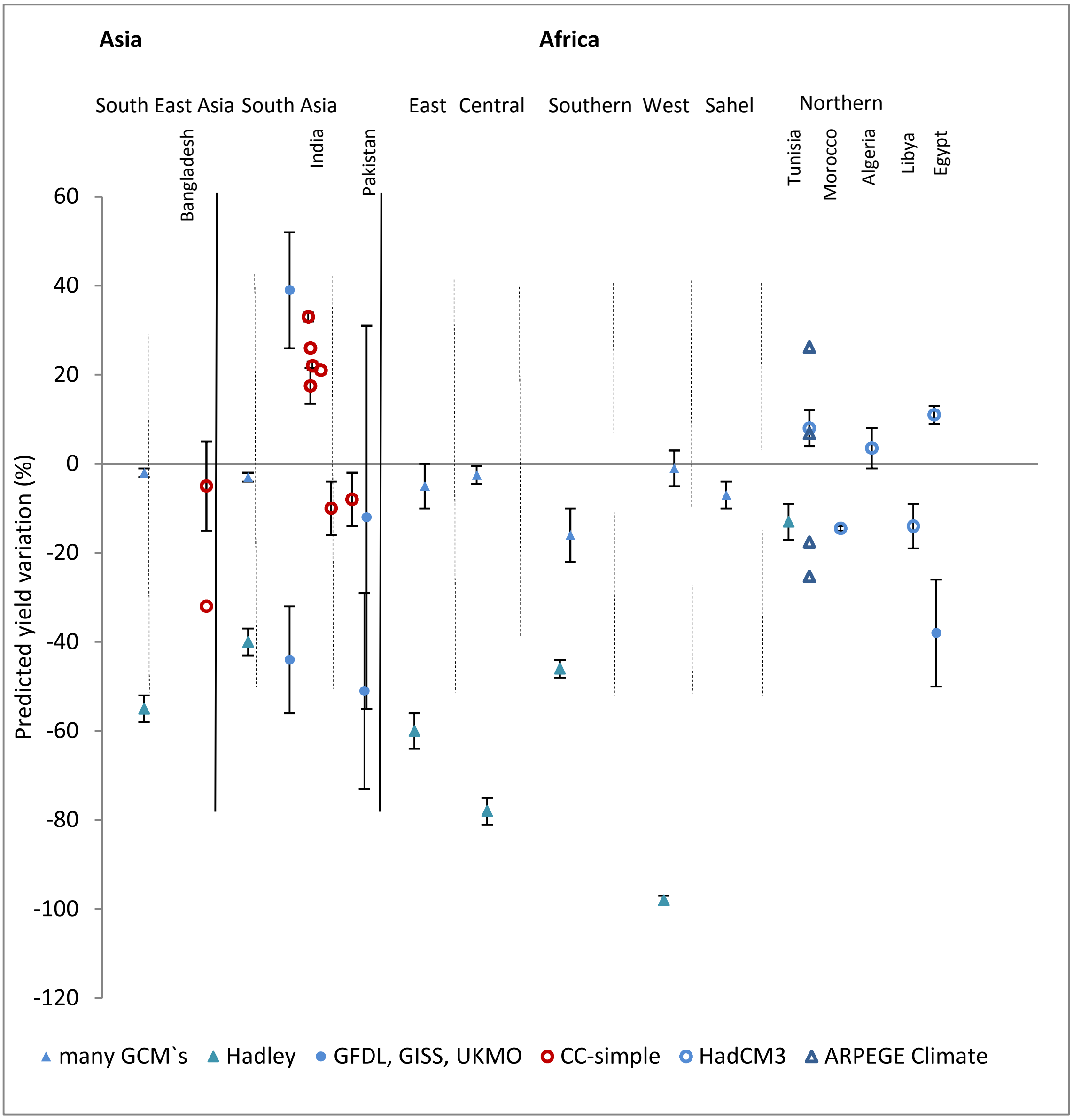
(c) 2080s


Asia
Africa
South East Asia
South Asia
East
Central
Southern
West
Sahel
Northern
Bangladesh
India
Pakistan
Tunisia
Morocco
Algeria
Egypt
Libya
Predicted yield variation (%)
50
40
30
20
10
0
-10
-20
-30
-40
-50
Lhomme et al. (2009)

4.3.2.4 Results by climate change methodology (CC-simple and CC-complex)

Figure 29 shows the projected impact on wheat yield variation using different approaches to climate change modelling (CC-simple and CC-complex).

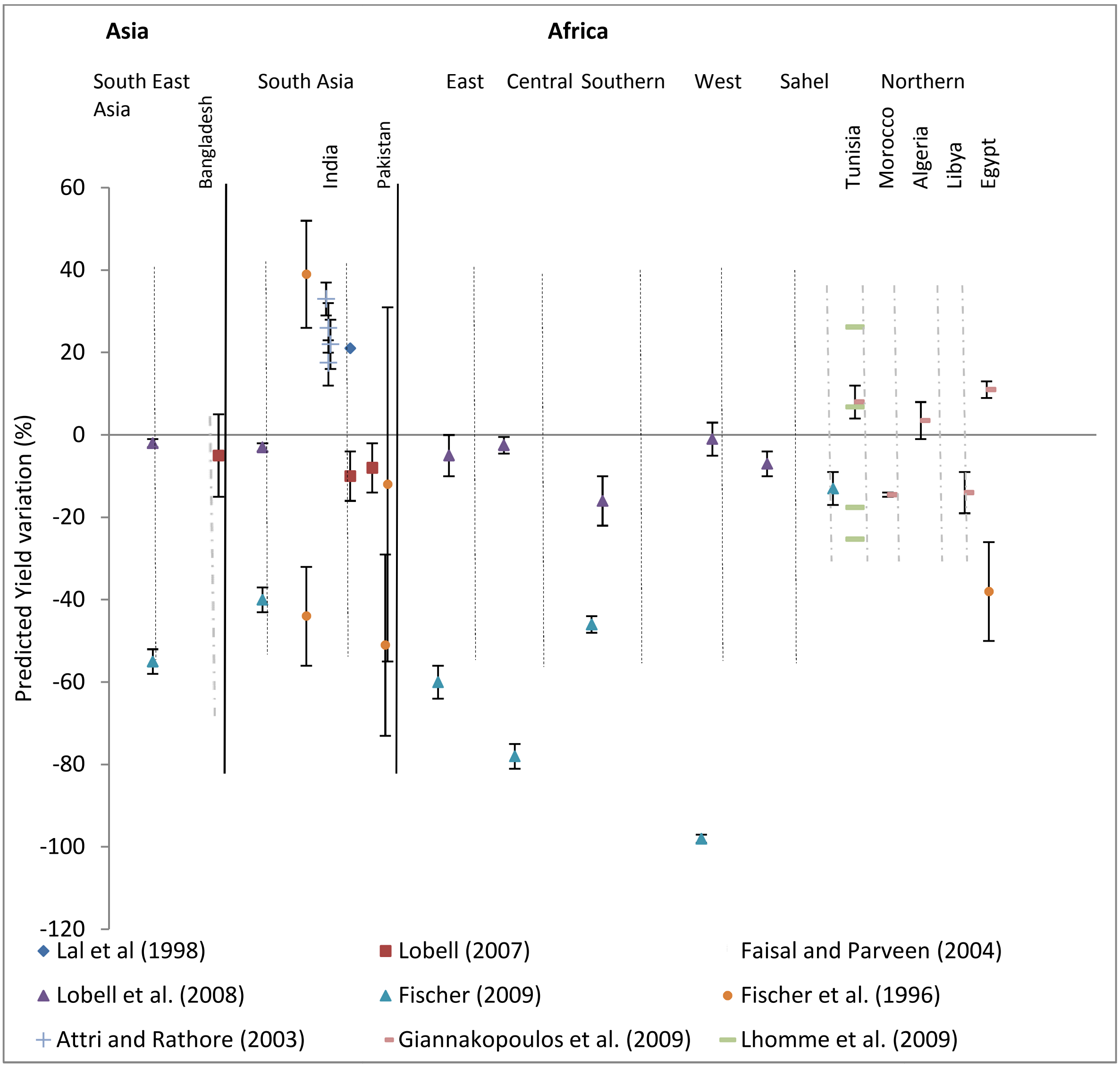
Figure 29 Reported variations (%) in wheat yield in S. Asia and Africa using different climate change modelling methods.



4.3.2.5 Results by CC-complex methodologies

Figure 30 shows the results for simulations carried out using CC-complex methodologies.

Figure 30 Reported variations (%) in wheat yield in S. Asia and Africa for CC-complex based methodologies.



4.3.3 Maize

4.3.3.1 Data sources

For this review, evidence on the impacts of climate change on maize productivity in Asia were drawn from 5 peer review papers (4 journals and a conference paper). For Africa, 22 studies were analysed with data extracted from 13 journals, two book chapters and conference proceedings (Table 11). Evidence was also drawn from Leemans and Solomon (1993) who published a study on climate change impacts on several crops including wheat in Africa and Asia. Within the literature, a number of studies provide data on a specific country basis.

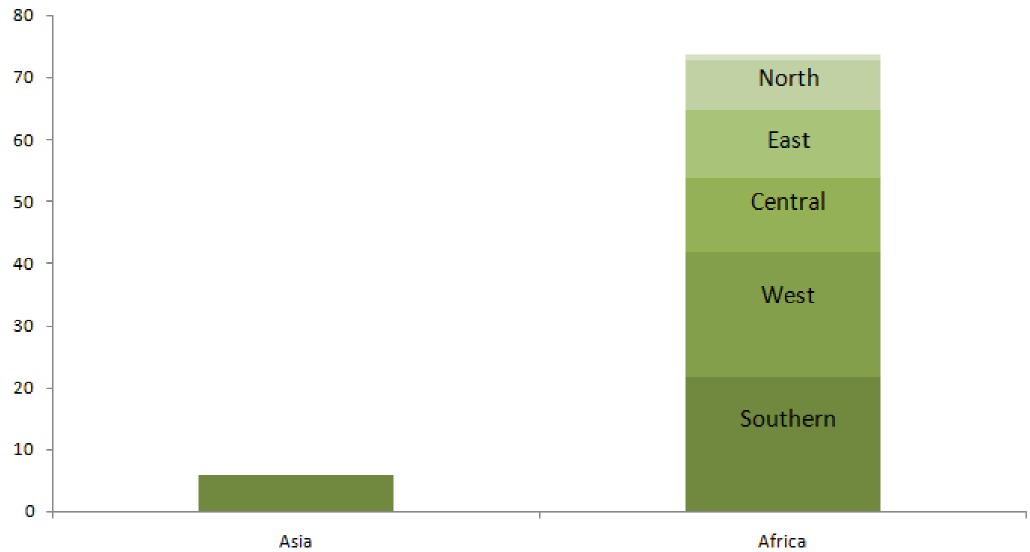
Table 11 Summary of literature included in the review for maize in Asia and Africa.

Author and year	Country/region	Journal title/report
ASIA		
Lobell (2007)	India	Agricultural and Forest Meteorology
Patel et al. (2008)	India	Journal of Agrometeorology
Lobell (2008)	Global	Science
Byjesh et al. (2010)	India	Mitigation & Adaptation Strategies for Global Change
Fischer (2009)	Global	Expert meeting How to Feed the World in 2050, FAO
AFRICA		
Butt et al. (2005)	Mali	Climatic Change
Tingem et al. (2008)	Cameroon	Agronomy for Sustainable Development
Tingem et al. (2009)	Cameroon	Climate research
Laux et al. (2010)	Cameroon	Agricultural and Forest Meteorology
Lobell and Burke (2010)	Sub-saharan	Agricultural and Forest Meteorology
Chipanshi et al. (2003)	Botswana	Climatic change
Adejuwon (2005)	Nigeria	Singapore Journal of Tropical Geography
Blignaut et al. (2009)	South Africa	South African Journal of Science
Walker and Schulze (2008)	South Africa	Agriculture, Ecosystems and Environment
Mati (2000)	Kenya	Journal of Arid Environments
Walker and Schulze (2008)	South Africa	Physics and Chemistry of the Earth
Giannakopoulos et al. (2009	Morocco, Algeria, Tunisia, Libya, Egypt	Global and Planetary Change
Gbetibouo and Hassan (2005)	South Africa	Global and Planetary Change
Thornton et al. (2009	Eastern Africa	Global Environmental Change
Schulze et al (1993)	Southern Africa	Global Environmental Change
Jones and Thornton (2003)	Angola, Benin, Botswana, Burkina Faso, Burundi, Cameroon, Central Africa, Chad, DR Congo, Congo, Côte d'Ivoir, Equatorial Guinea, Eritrea, Ethiopia, Gabon, Gambia, Ghana, Guinea, Guinea-Bissau, Kenya, Lesotho, Liberia, Madagascar,	Global Environmental Change

	Malawi, Mali, Mauritania, Morocco, Mozambique, Namibia, Niger, Nigeria, Rwanda, Senegal, Sierra Leone, Somalia, Sudan, Swaziland, Tanzania, Togo, Uganda, Zambia, Zimbabwe	
Abraha and Savage (2006)	South Africa	Agriculture, Ecosystems and Environment
Makadho (1996)	Zimbabwe	Climate Research
Muchena and Iglesias (1995)	Zimbabwe	Climate Change and Agriculture: Analysis of Potential International Impacts (Book)
Odingo (1990)	Continantal	Soils on a Warmer Earth (Book)
Lobell et al (2008)	Global	Science
Fischer (2009)	Global	FAO Expert Meeting on How to Feed the World in 2050

Other studies report their findings for larger regions: Jones and Thornton (2003), Lobell et al. (2008), Leemans and Solomon (1993), Odingo (1990), Fischer (2009), Thornton et al. (2009), Schulze et al (1993), Lobell and Burke (2010). An overall summary of the published sources for each sub-region in Asia and Africa is given in Figure 31. However, it is important to note that in some instances a single publication (e.g. Jones and Thornton, 2003) can often refer to a large number of countries, thus distorting the split between regions.

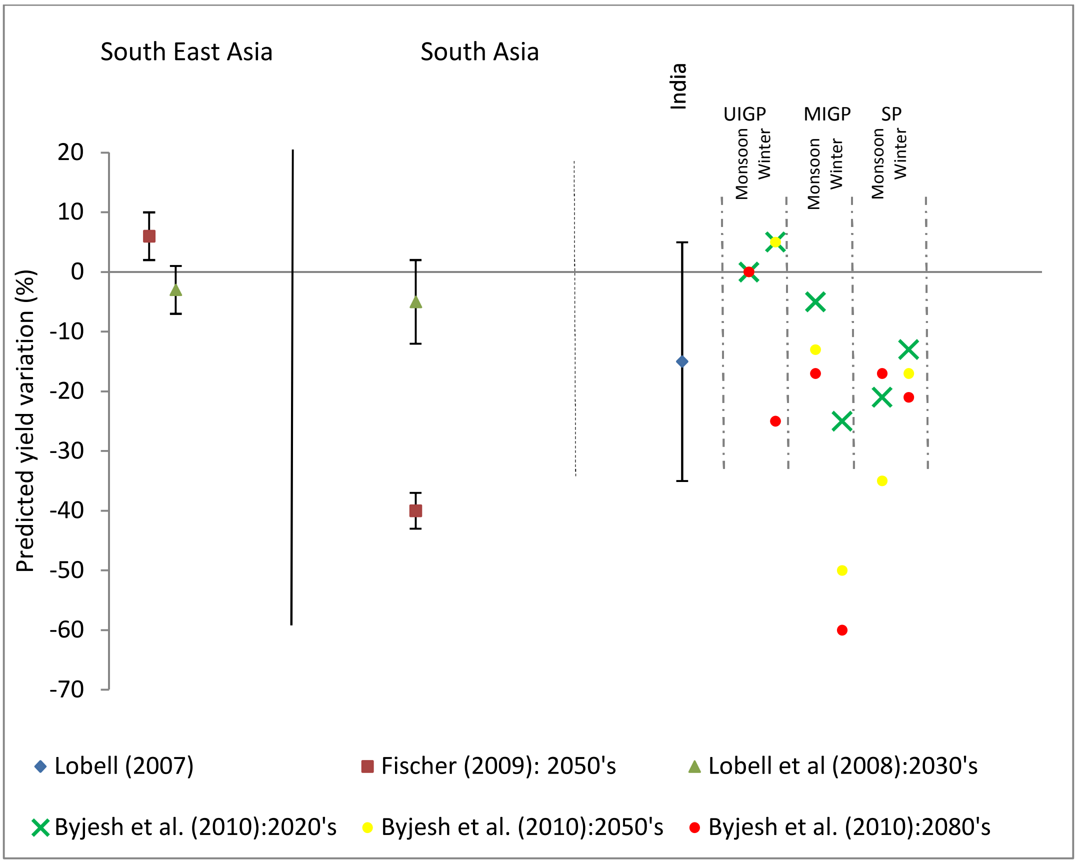
Figure 31 Number of published data sources used for assessing climate change impacts on maize in Africa and Asia.



4.3.3.2 *Overall results*

Figure 32 shows the projected variations in maize yield in Asia for all time slices, and the results of the scenarios simulated by Lobell (2007) who predicted yield using increasing average temperature and the diurnal temperature range. The results of the study driven by Byjesh et al. (2010) are given for monsoon and winter maize for 3 regions in India: the Upper Indo-Gangic Plain (UIGP), Middle and Eastern Ingo-Gangic Plain (MIGP), and Southern Plateau (SP).

Figure 32 Reported variation in maize yield with climate change in Asia for all time slices and by increasing average temperature and diurnal temperature range.



4.3.3.3 *Results by time slice*

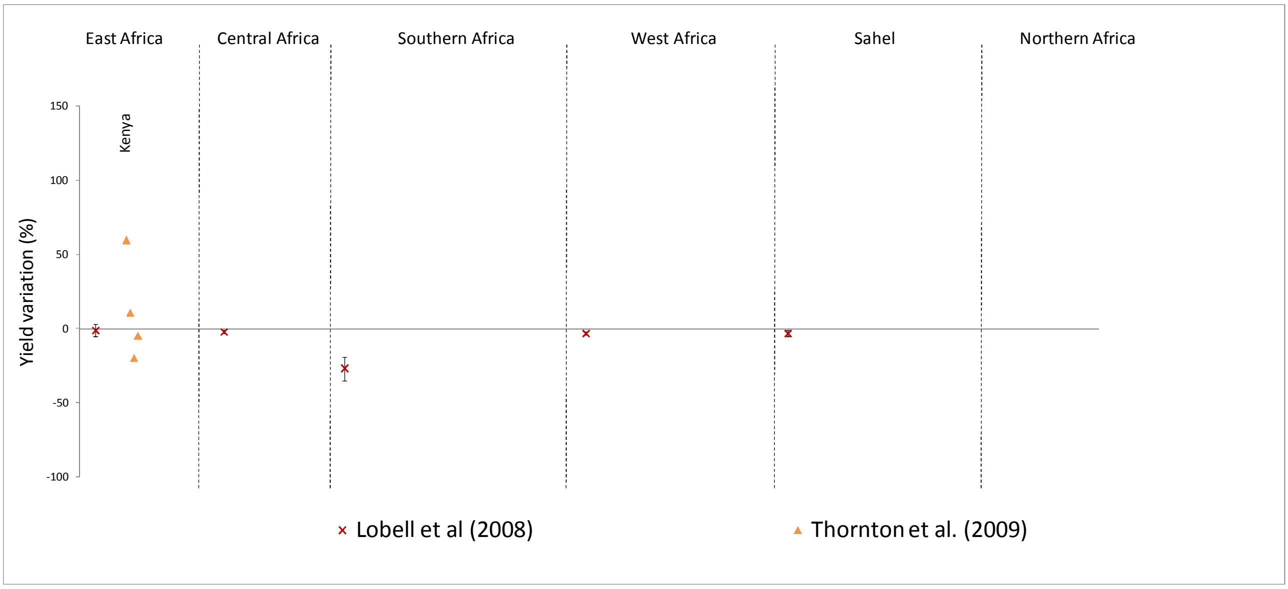
Figure 33 shows the predictions in maize yield variation for all time slices (2020s, 2030s, 2050s, and 2080s) in Africa. For the 2020s, results relate to Cameroon (Laux et al., 2010; Gbetibouo and Hassan, 2005) and for 4 regions in Kenya (Thornton et al., 2009). The impacts of climate change in the 2020’s appear to be positive in Cameroon, and West and central Kenya, where the increase in productivity could be as much as 30% (Thornton et al., 2009). The forecasted yield variation for the decade of the 2030’s contains the predictions of the global study by Lobell et al. (2008), and the work on Kenyan productivity from Thornton et al. (2009), and Mati (2000). Climate change effects will be positive in Kenya (60% and 10% increase estimated by Thornton et al., 2009; and only in Kichaka Simba the estimated yield variation is negative, against the other 3 regions (Mati, 2000).

Figure 33c shows what the variation in productivity in the 2050’s will look like according to Fischer (2009) and Thornton et al. (2009) for large regions, and to Giannakopoulos et al. (2009), Byjesh et al. (2010), Chipanshi et al. (2003), Thornton et al. (2009),and Jones and Thornton (2003) for several countries. It has to be noted, that the original work of Giannakopoulos et al. (2009) expresses the yield variation for 2031-2060, but has been included in this as part of the predictions for the 2050s. Most of the predictions for this decade are negative, however, for some regions like West Kenya, Lesotho and Morocco the predictions are positive. According to Fischer (2009), maize yield variation will be positive in East, Central and Northern Africa. The forecasted yield variation in Africa for the 2080s includes data from Tingem et al. (2009) and Laux et al. (2010). The effects of climate change are forecast to negatively affect maize productivity in Cameroon in the 2080s (see Figure 33d).

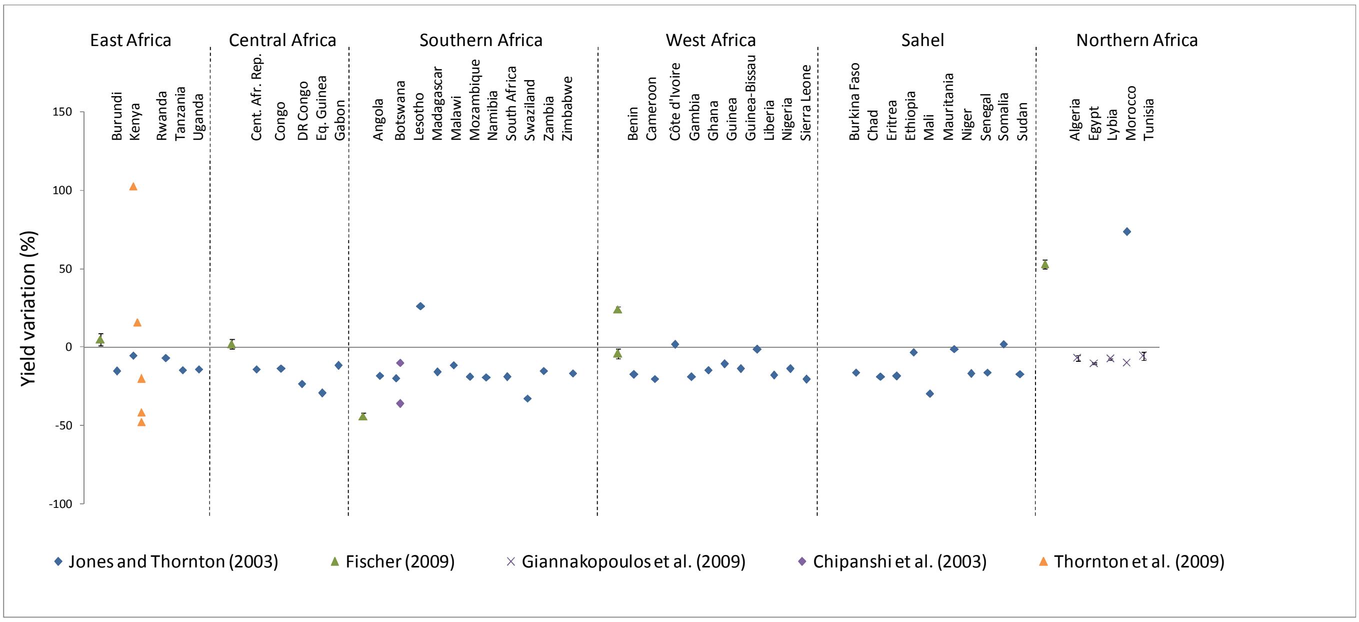
Figure 33 Summary of projected variations in maize yield (%) in Africa by time slice.

(a) 2020s

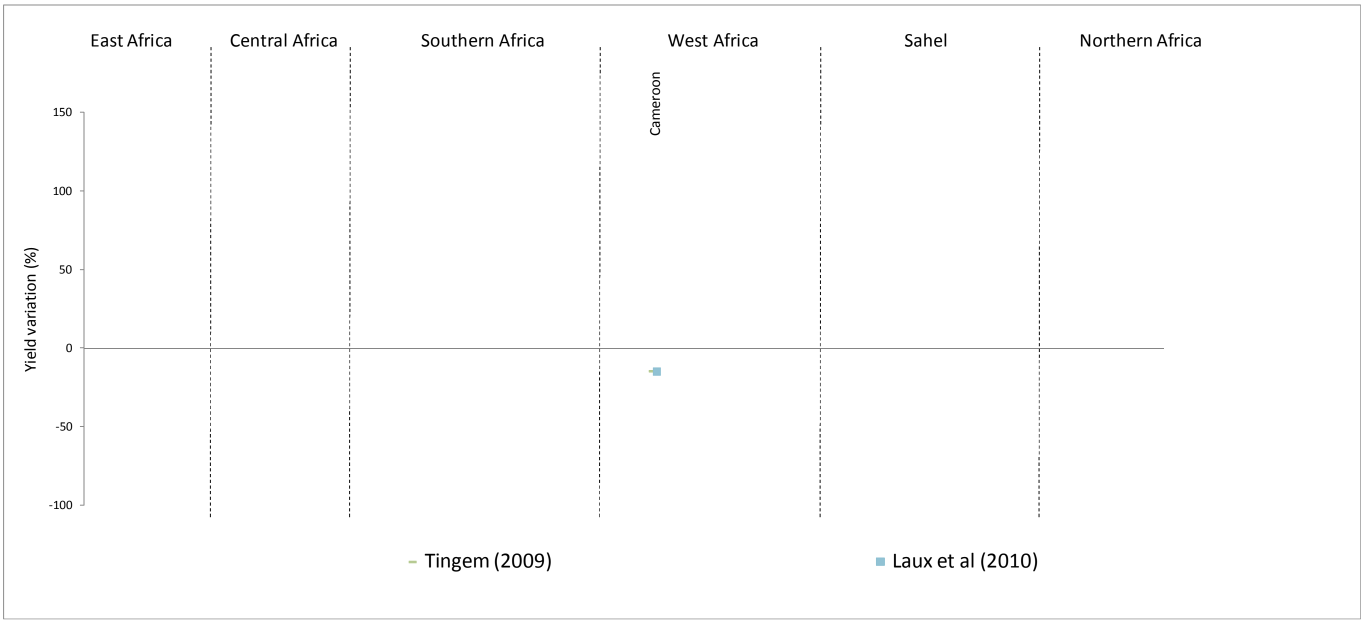
(b) 2030s



(c) 2050s



(d) 2080s



4.3.3.4 Results by climate change methodology (CC-simple and CC-complex)

Figure 34 and Figure 35 present the results for future maize yield variation in S. Asia and Africa, respectively, based on both CC-simple and CC-complex models.

Figure 34 Summary of reported variations in maize yield (%) in S. Asia using different climate methods (CC-simple and CC-complex).

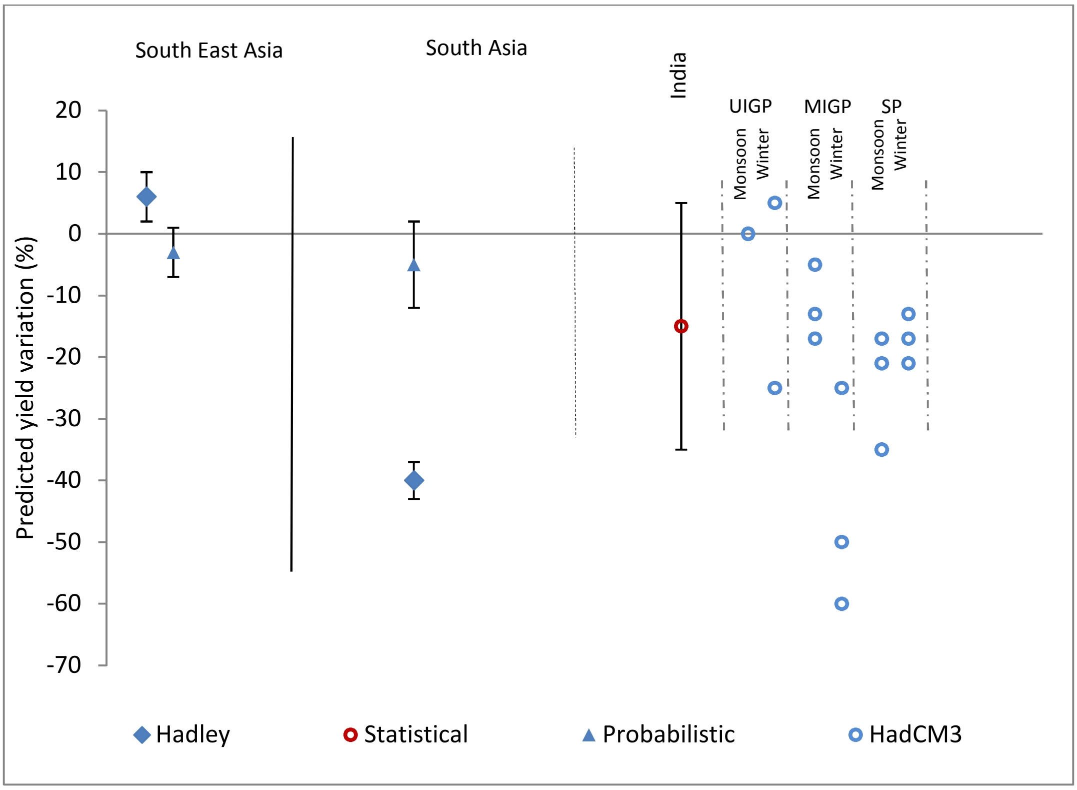
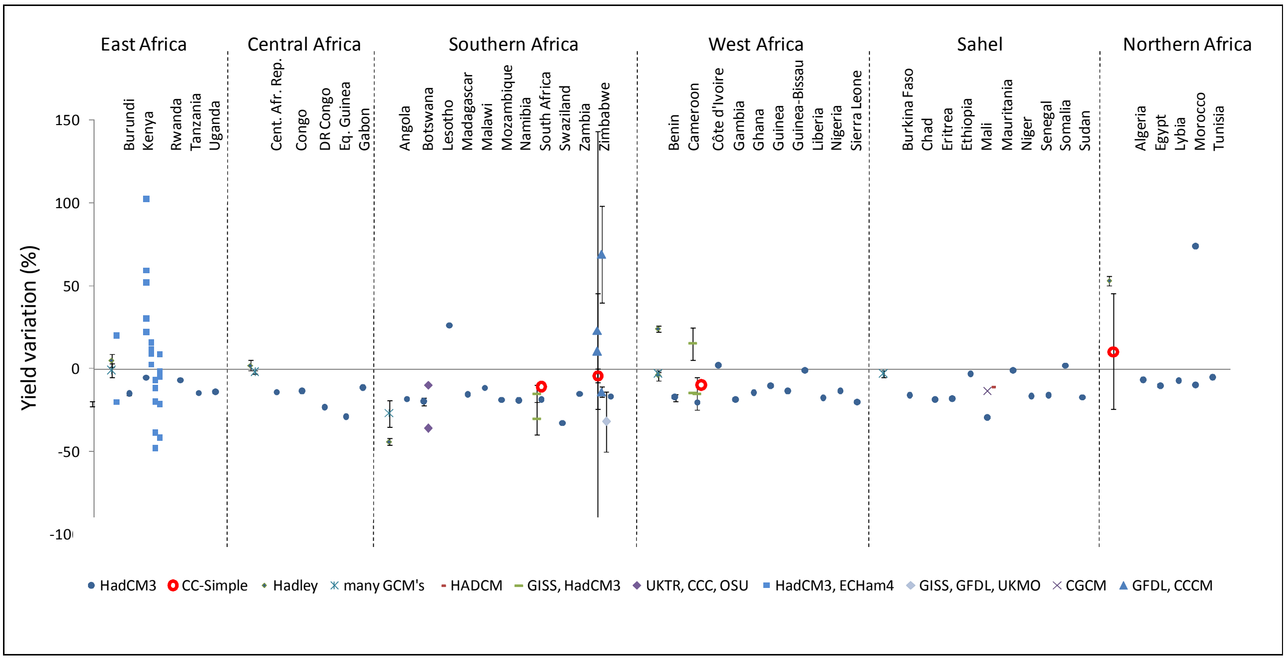


Figure 35 Summary of projected variations in maize yield (%) in Africa with different methods (CC-simple and CC-complex).



4.3.3.5 *Results by climate change methodology (CC-complex)*

Figure 36 Summary of projected variations in maize yield (%) in Africa for all time slices, based on CC-complex methodologies.

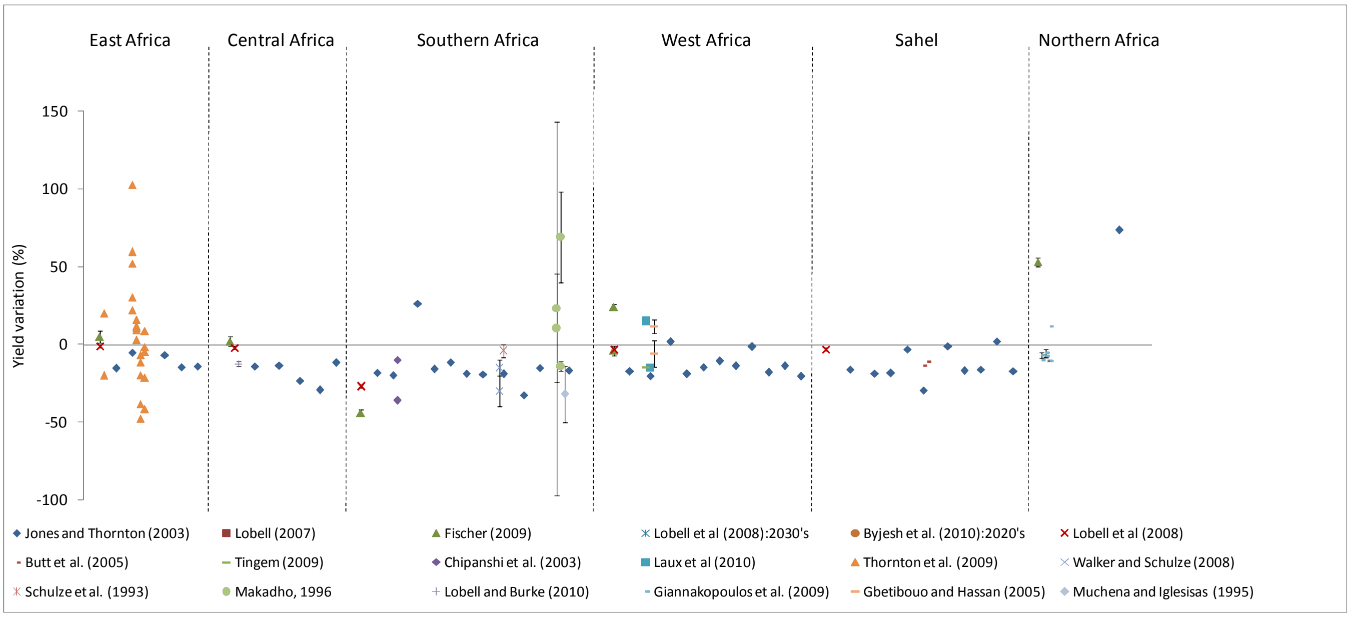
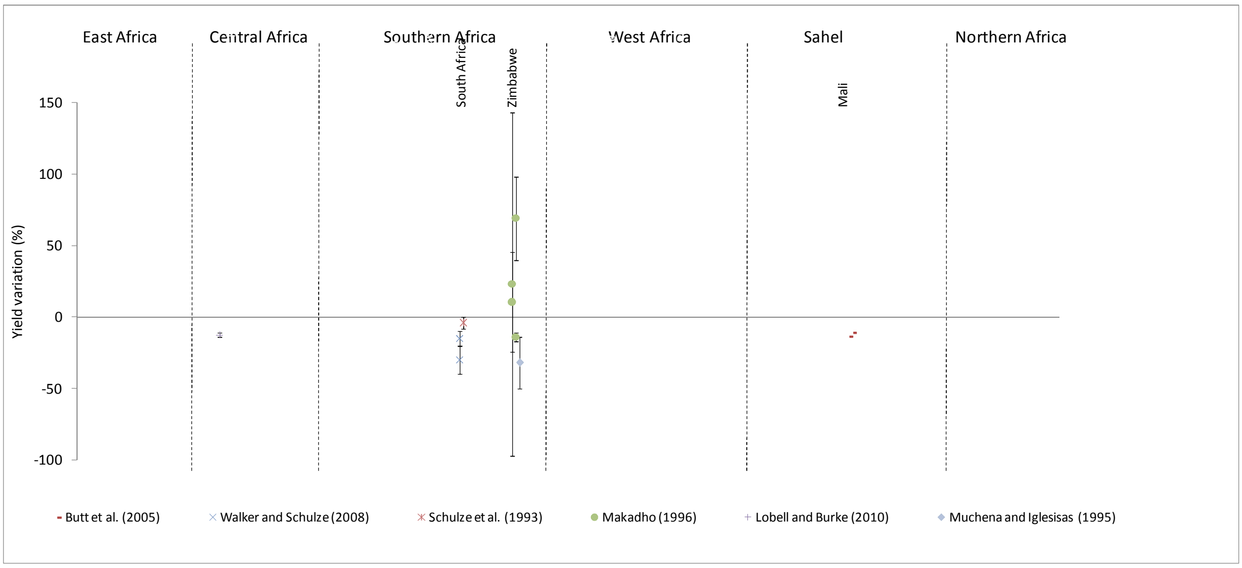


Figure 37 shows the results of Butt et al. (2005), Odingo (1990), Thornton et al. (2009), Walker and Schulze (2008), Schulze et al. (1993), Makadho, (1996), Lobell and Buerke (2010), and Muchena and Iglesias (1995), for different GCM's (Walker and Schulze, 2008; Muchena and Iglesias, 1995) and fix scenarios (Lobell and Burke, 2010). The predicted effects are negative for Mali (Butt et al., 2005), South Africa (Schulze et al., 1993; Walker and Schulze, 2008) and Central Africa (Lobell and Burke, 2010). In Zimbabwe, Makadho (1996) predicted positive effects (up to 140%) in different location and under different planting dates, while Muchena and Iglesias (1995) predicted yield variations of -50% to -14% in others.

Figure 37 Predicted variation of maize yield under climate change effects in Africa using GCM's (GISS, GFDL, UKMO, HadCM2, and CSM) and non specific time slices.



4.3.4 Sorghum

4.3.4.1 Data sources

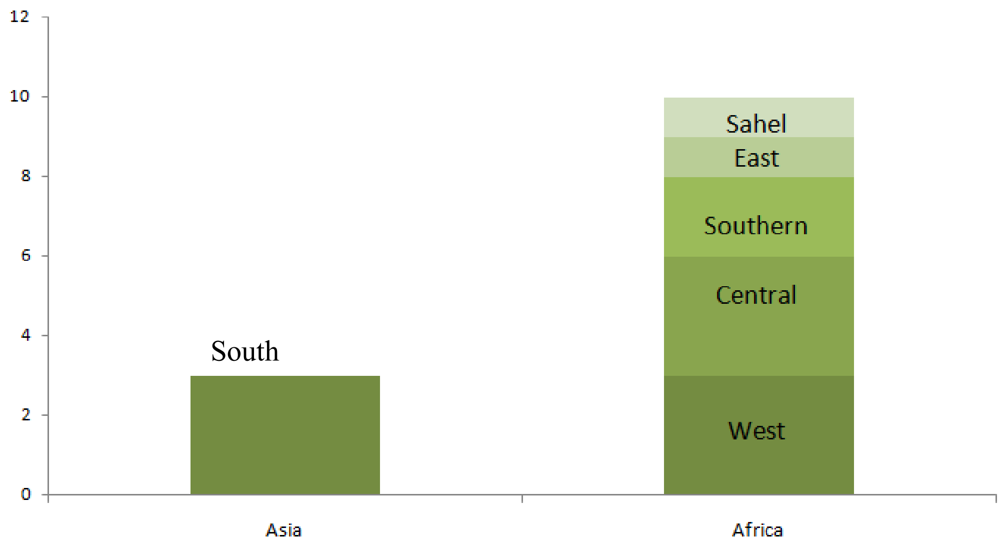
For this review, evidence on the impacts of climate change on sorghum productivity in Asia was drawn from 3 peer review papers (2 journals and a book chapter). For Africa, 7 papers were analysed with data extracted from 6 journals (Table 12).

Table 12 Summary of literature included in the review for sorghum in S. Asia and Africa.

Author and year	Country/region	Journal title/report
ASIA		
Lobell et al (2008)	Global	Science
Srivastava et al. (2010)	India	Agriculture, Ecosystems and Environment
Rao et al. (1995)	India	Climate change and agriculture: analysis of potential international impacts
AFRICA		
Lobell et al. (2008)	Global	Science
Tingem et al. (2009)	Cameroon	Agronomy for Sustainable Development
Tingem et al (2008)	Cameroon	Climate Research
Butt et al. (2005)	Mali	Climatic Change
Chipanshi et al. (2003)	Botswana	Climatic Change
Gbetibouo and Hassan (2005)	South Africa	Global and Planetary Change
Adejuwon (2005)	Nigeria	Singapore Journal of Tropical Geography

Many of the studies are country specific, for example, Tingem et al. (2008; 2009) focus in Cameroon, Butt et al. (2005) in Mali, Chipanshi et al. (2003) in Botswana, Gbetibouo and Hassan (2005) in South Africa, Adejuwon (2005) in Nigeria, and Srivastava et al. (2010) and Rao et al. (1995) in India. The study reported here by Lobell et al (2008) provides a global assessment. As before, data from Adejuwon (2005) and Gbetibouo and Hassan (2005) are not included in the following analyses, since their data is not compatible with the other studies. An overall summary of the published sources for each sub-region in Asia and Africa is given in Figure 38.

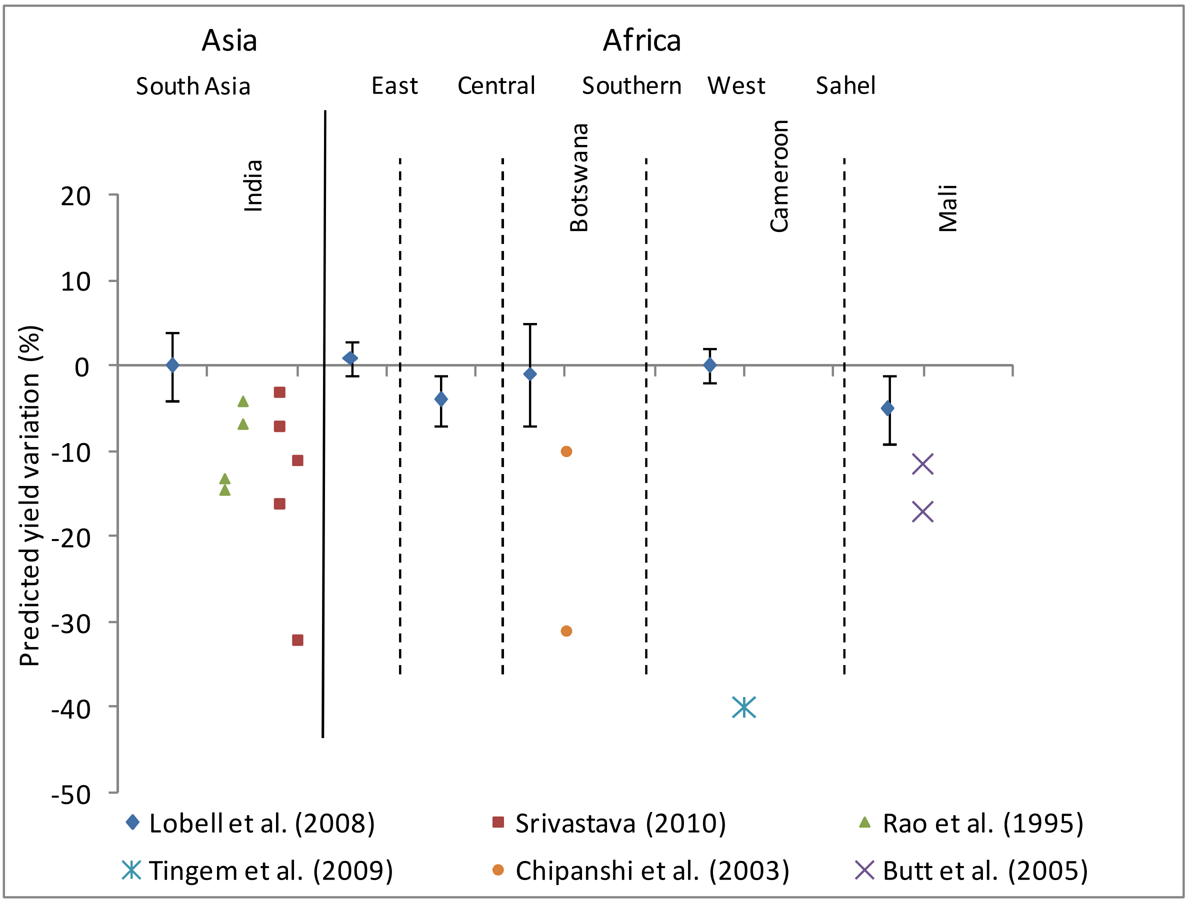
Figure 38 Number of published data sources used for assessing climate change impacts on sorghum in Africa and Asia.



4.3.4.2 Overall results

A summary of the results for all observations for sorghum in S. Asia and Africa is given Figure 39.

Figure 39 Reported variation in sorghum yield with climate change in Asia and Africa for all observations.

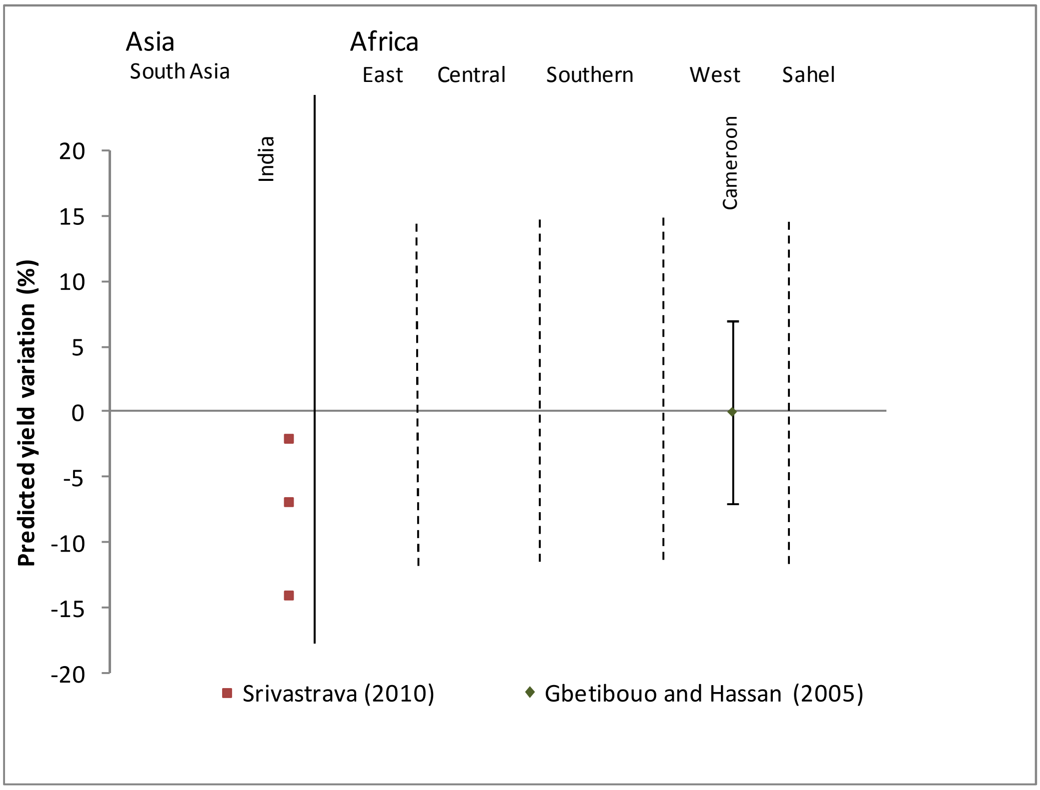


4.3.4.3 Results by time slice

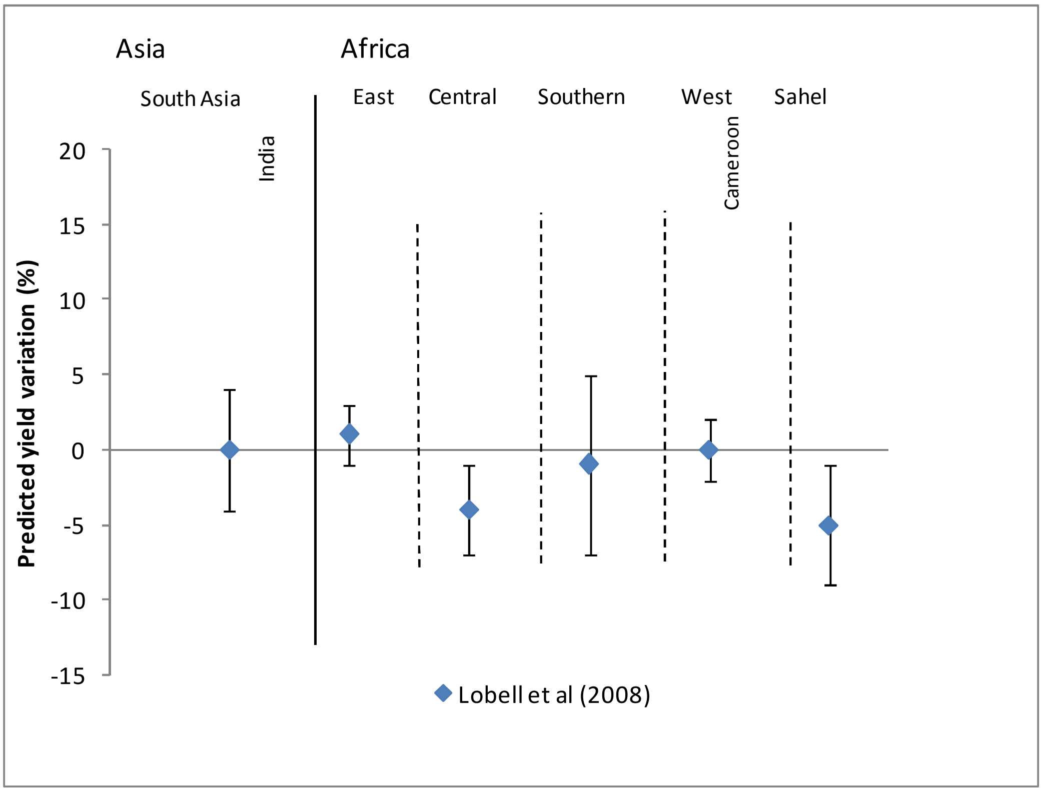
Figure 40 shows the predicted variation in yield productivity for the time period of the 2020's. It shows the results of Srivastrana (2010) for India. Sorghum yield is predicted to reduce in the 2020's by 2% in the South-Central Zone (SCZ), and by 14% in the Central Zone (CZ) and South-West Zone (SWZ) in monsoon season. Winter productivity was estimated to reduce by 7% (Srivastava, 2010).

Figure 40 Summary of projected variations in sorghum yield (%) in Asia and Africa by time slice.

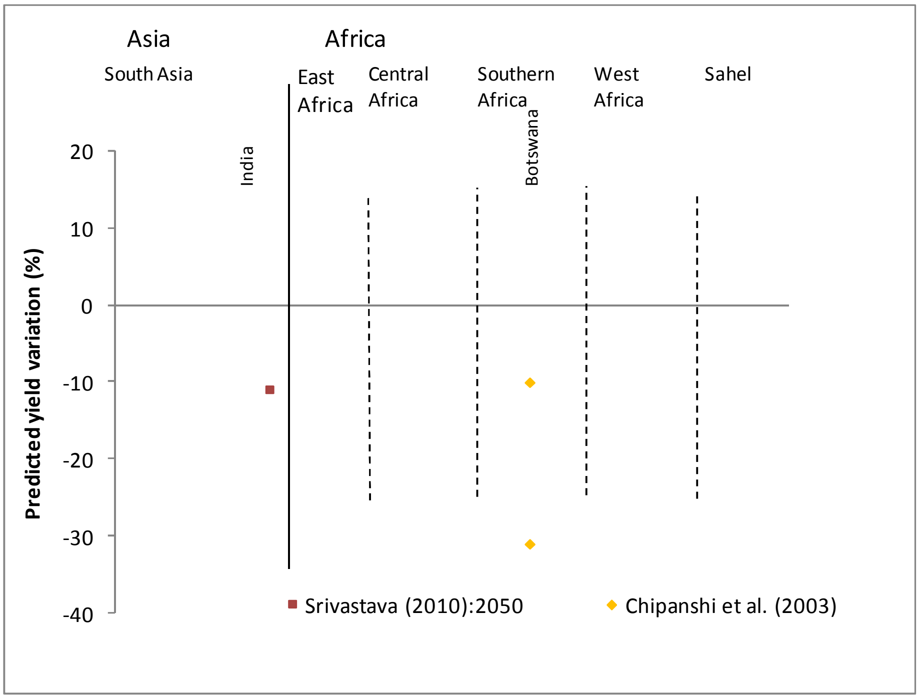
(a) 2020s



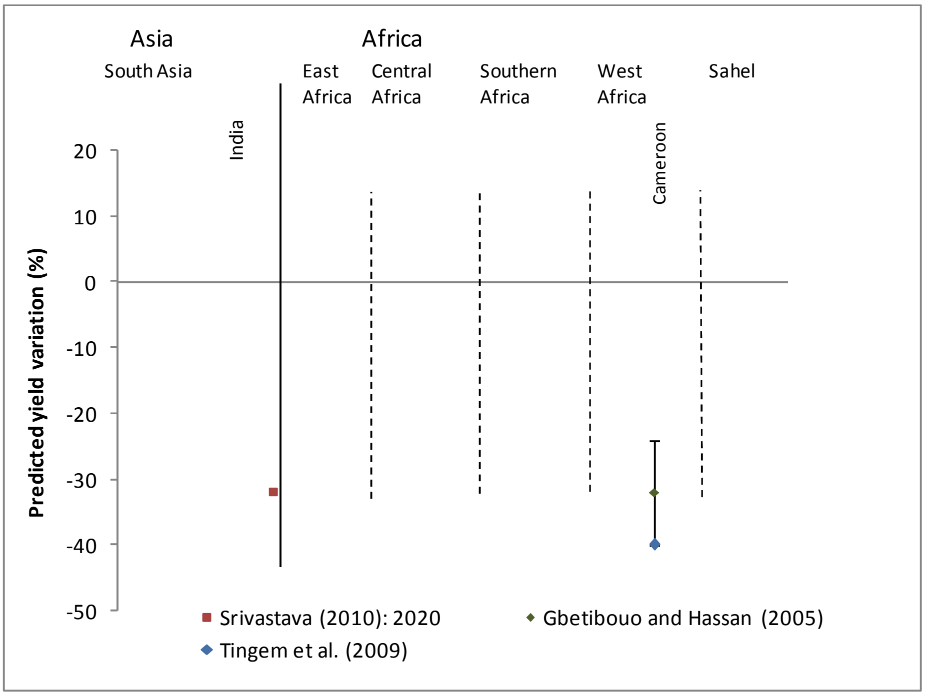
(b) 2030s



(c) 2050s



(d) 2080s



In Figure 41 the projections for the 2020s (green), 2050s (red) and 2080s (blue) shows the forecast changes in sorghum productivity over time. It is apparent that yield is forecast to reduce in India.

Figure 41 Predicted variation of sorghum yield productivity under climate change effects in Africa and Asia, by the 2020s, 2050s, and 2080s.

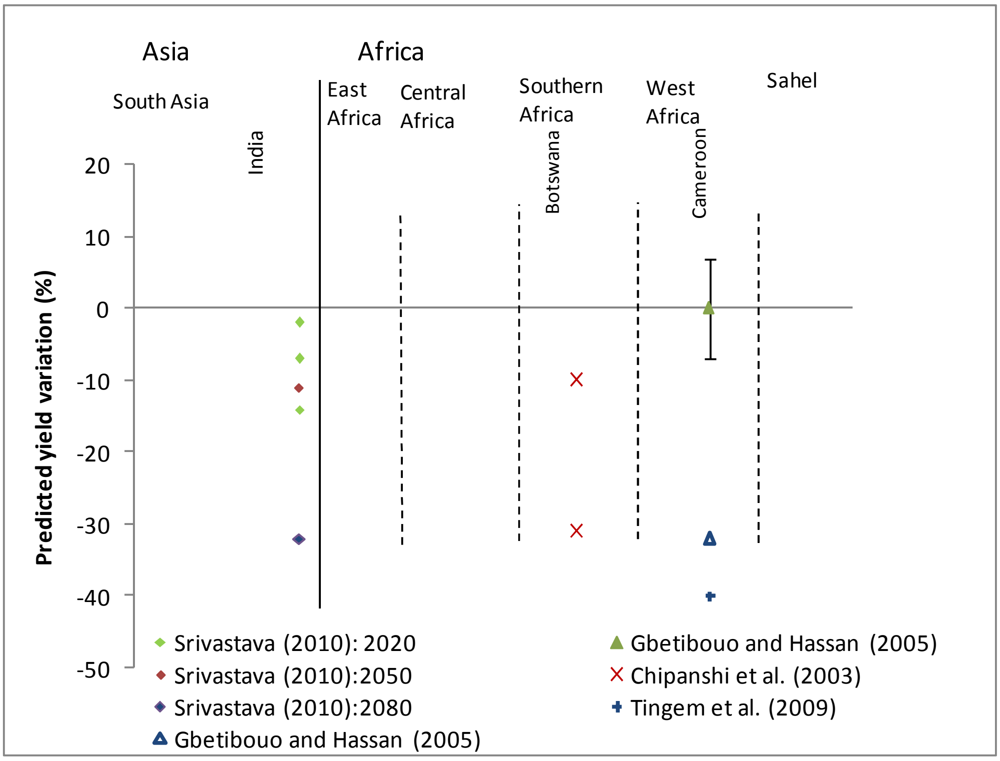
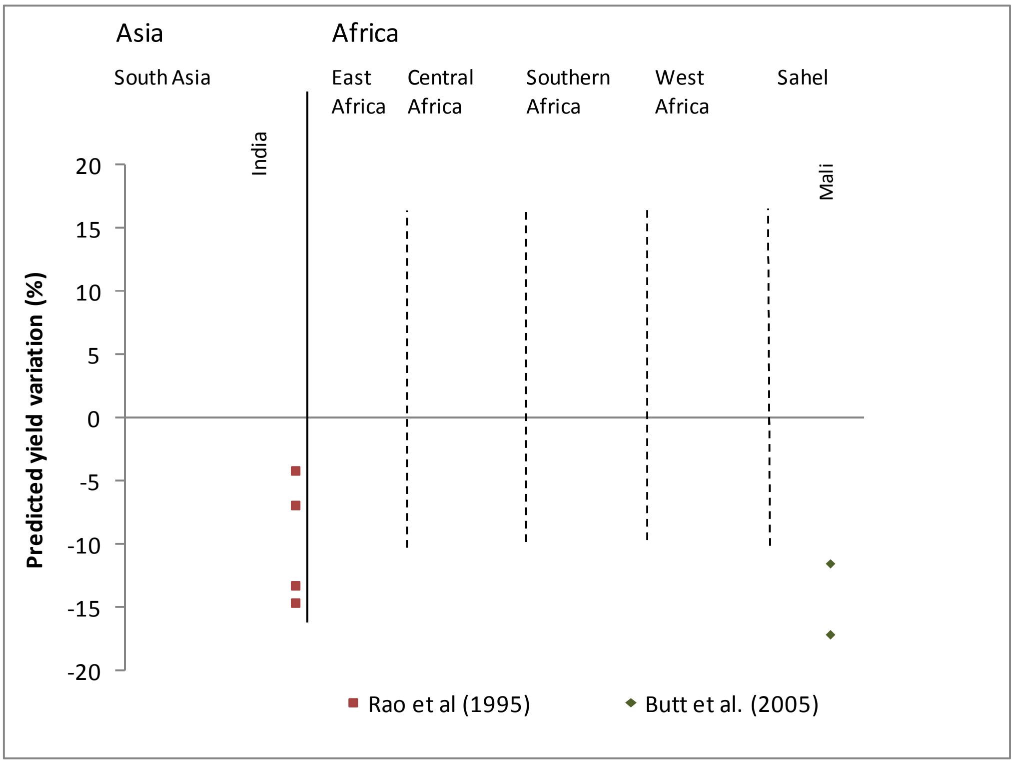


Figure 42 shows the variation obtained using the HadCM and CGCM GCMs (Butt et al., 2005) and fixed scenarios combining CO_2 atmospheric concentration variations and crop stress status.

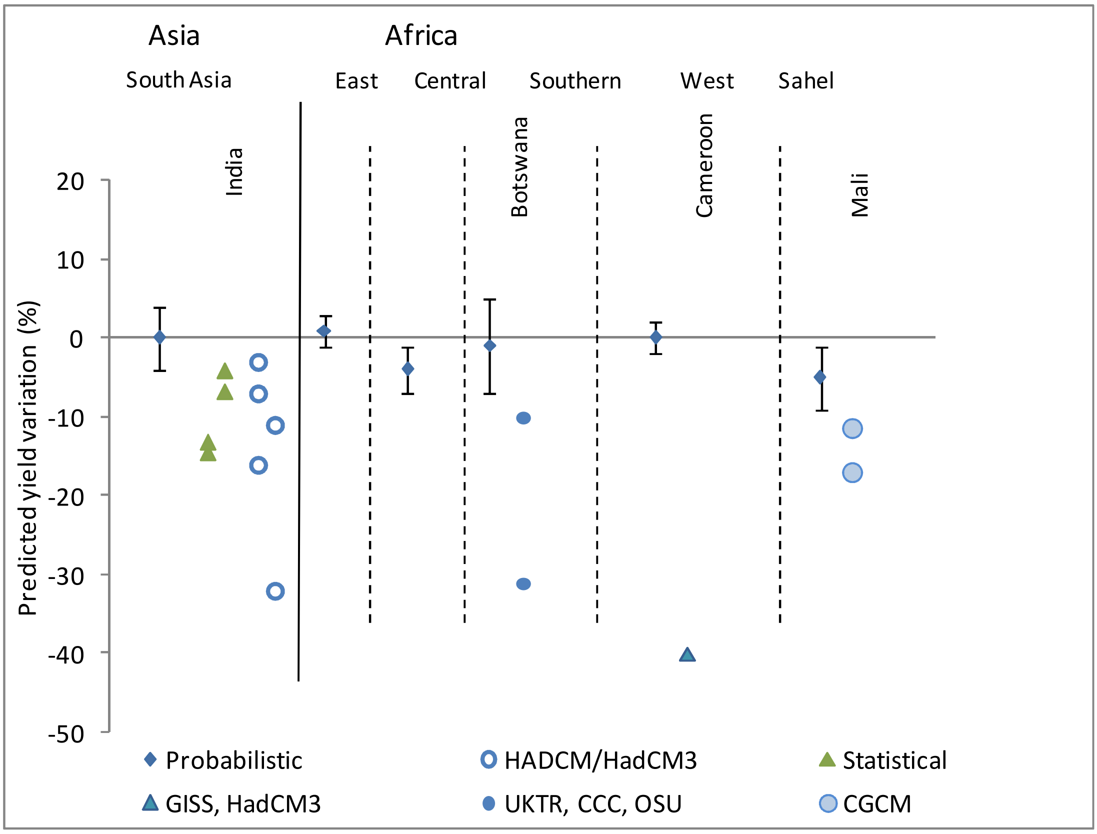
Figure 42 Predicted variation of sorghum yield productivity under climate change effects in Africa and Asia, based on predictions using GCM's (HadCM and CGCM) and fixed scenarios.



4.3.4.4 Results by climate change methodology (CC-simple and CC-complex)

Figure 43 shows the same data but grouped according to the methodology used to estimate future climatic conditions. The general trend is negative. Only in Eastern Africa is productivity projected to increase according to Lobell et al. (2008). However, the variability is high, with approximately a 50% probability of a positive impact in many cases.

Figure 43 Projected variation of sorghum yield with climate change in Africa and Asia based on CC-simple and CC-complex methodologies.



4.3.5 Millet

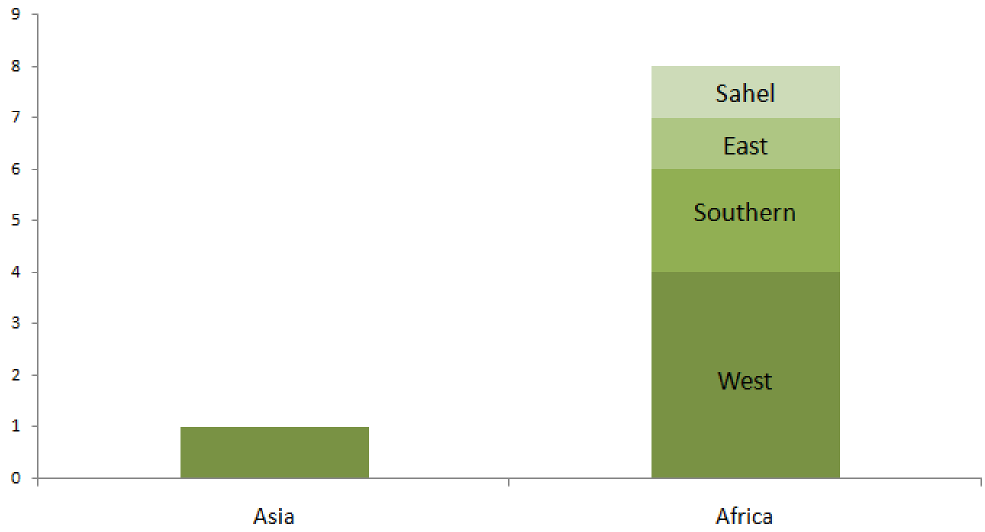
4.3.5.1 Data sources

For this review, evidence on the impacts of climate change on millet productivity in Asia was drawn from only 1 peer review paper. For Africa, 5 articles were analysed with data extracted from 4 journals (Table 13). A summary of the published sources for each sub-region in Asia and Africa is given in Figure 44.

Table 13 Summary of literature included in the review for millet in S. Asia and Africa.

Author and year	Country/region	Journal title/report
AFRICA		
Lobell et al. (2008)	Global	Science
Butt et al. (2005)	Mali	Climate Change
Mohamed (2002)	Niger	Climate Change
Adejuwon (2005)	Nigeria	Singapore Journal of Tropical Geography
Gbetibouo and Hassan (2005)	South Africa	Global and Planetary Change

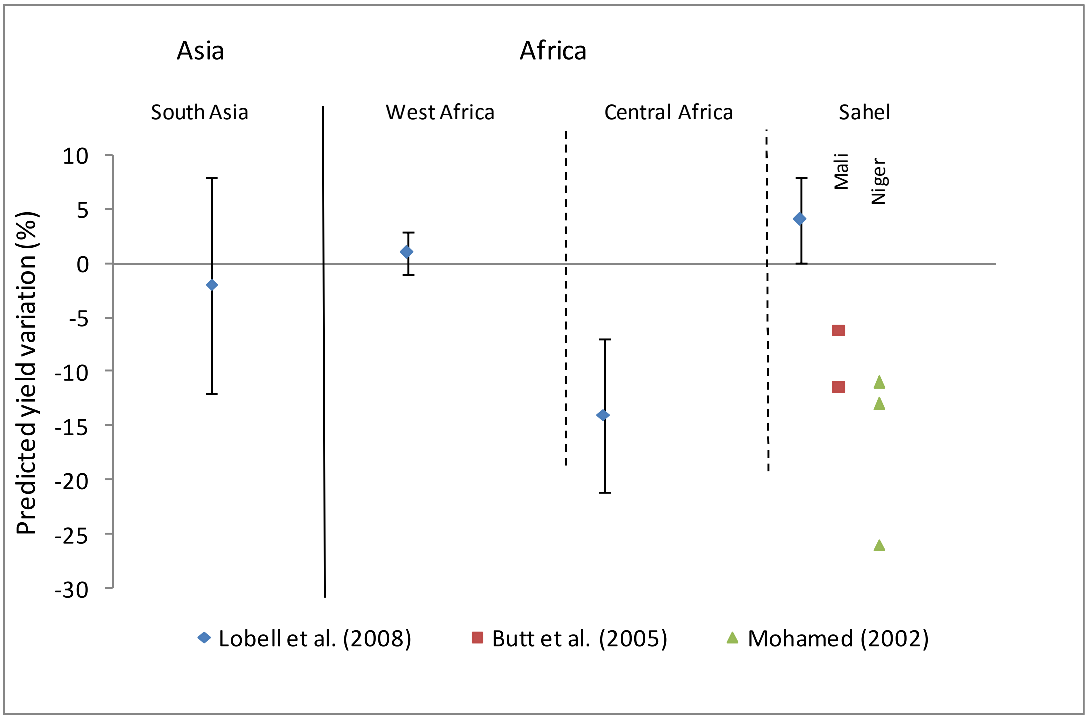
Figure 44 Published results for climate change effects on millet given for each sub region in Africa and Asia.



4.3.5.2 Overall results

Figure 45 shows the forecasted millet yield variations estimated using the GCM's HadDC and CGCM (Butt et al., 2005), studying different possible scenarios (Mohamed, 2002) and as the result of a probabilistic study (Lobell et al., 2008). Mohamed (2002) predicted a negative variation in millet productivity in 3 different regions in Niger for the year 2025. At the worst scenario (20% increase in temperature, 20% decrease in rainfall) the predictions were of 26% decrease at 2 of the 3 studied areas. The forecasted effects were negative for Mali and Niger. Lobell et al. (2008) give a wide range of results being most of them positive for the Sahel and West Africa and negative for Central Africa. In South Asia the variation could be according to this probabilistic study positive as well as negative, but in any case the variation would be smaller than 15%.

Figure 45 Estimated millet yield variations according to Lobell et al. (2008), Butt et al. (2005), and Mohamed (2002) for the 2030s.

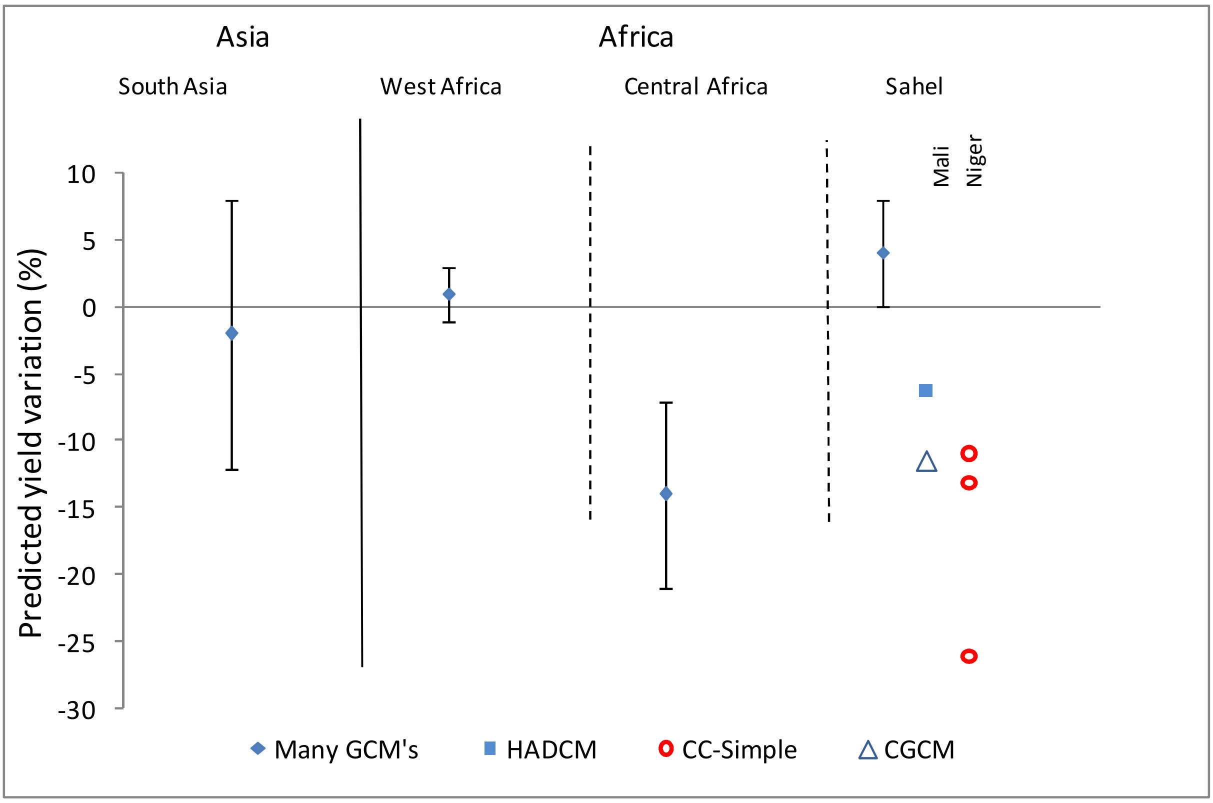


4.3.5.3 *Results by time slice*

Insufficient data for analysis

4.3.5.4 Results by climate change methodology (CC-simple and CC-complex)

Figure 46 Summary of projected variations in millet yield based on different climate modelling methods.



4.3.5.5 Results by climate change methodology (CC-simple)

Insufficient data for analysis. See Figure 44.

4.3.5.6 Results by climate change methodology (CC-complex)

Insufficient data for analysis. See Figure 44.

4.3.6 Cassava

4.3.6.1 Data sources

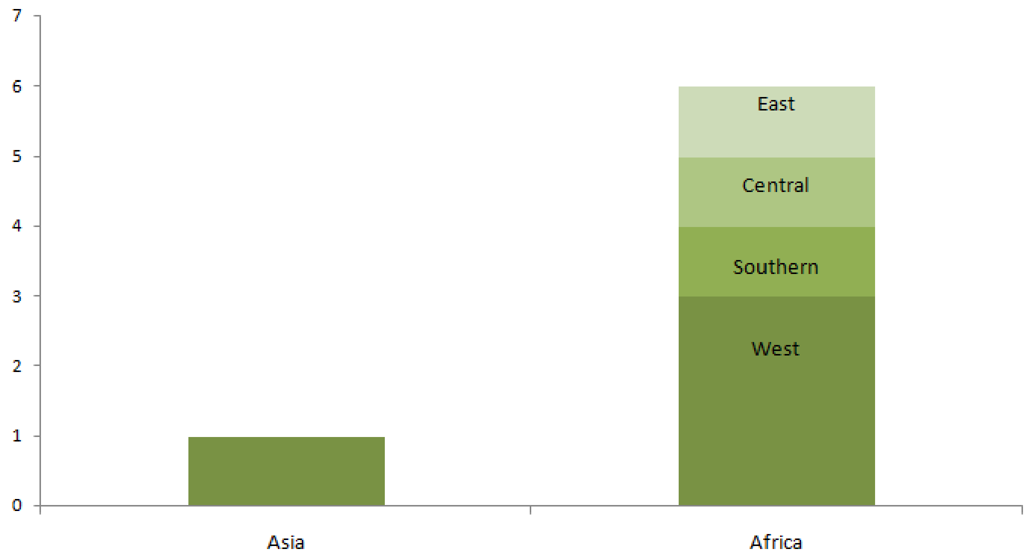
For this review, evidence on the impacts of climate change on cassava productivity in Asia was drawn from 1 peer review paper. For Africa, 2 papers were analysed with data extracted from a journal and environmental report (Table 14).

Table 14 Summary of literature included in the review for cassava in S. Asia and Africa.

Author and year	Country/region	Journal title/report
ASIA		
Lobell et al. (2008)	Global	Science
AFRICA		
Lobell et al (2008)	Global	Science
Adejuwon (2005)	Nigeria	Singapore Journal of Tropical Geography
Sagoe (2008)	Ghana	Environmental Protection Agency (EPA), Accra-Ghana

The global probabilistic study by Lobell et al. (2008) presents the results at a continental or regional basis. A summary of the published sources for each sub-region in Asia and Africa is given in Figure 47.

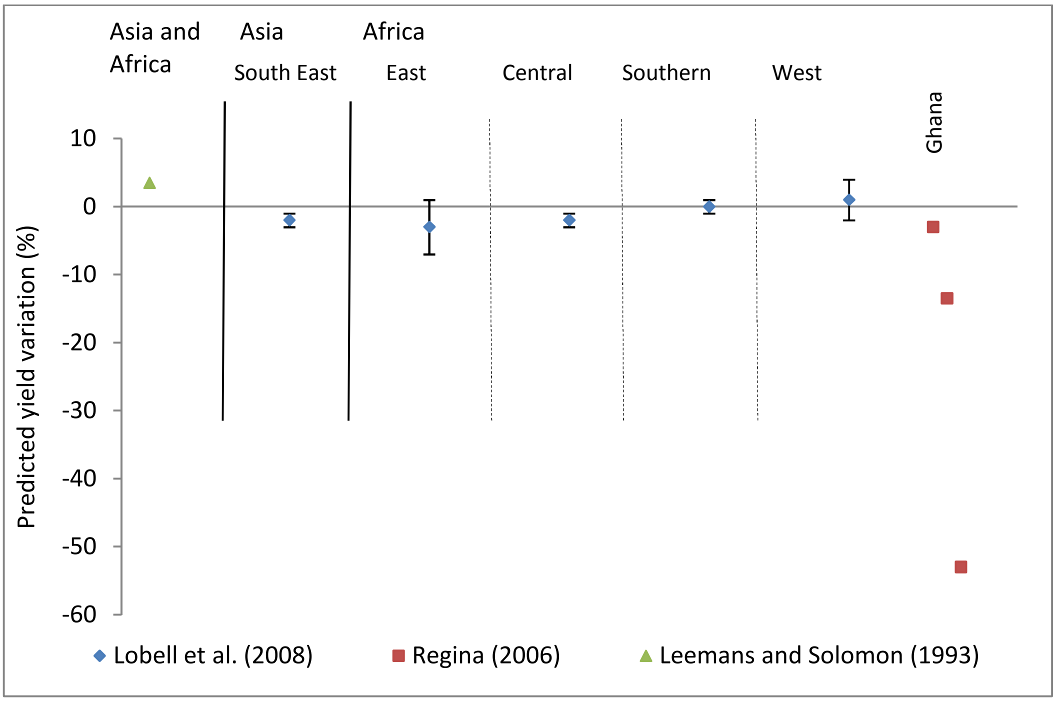
Figure 47 Number of published data sources used for assessing climate change impacts on cassava in Africa and Asia.



4.3.6.2 Overall results

Figure 48 shows the predicted yield variation in cassava crop productivity with climate change in Asia and Africa. The results are for the decade of the 2030's (Lobell et al., 2008), for two different locations and scenarios (Mohamed, 2002), and estimated using the GCM's HadCM and CGCM (Butt et al., 2005). Leemans and Solomon (1993) predict a small increase in the overall productivity of Asia and Africa. The forecasted variability is positive for West African cassava productivity (Lobell et al., 2008), but not for Ghana, where by 2080 the decrease will be up to 53% (Regina, 2006). In South East Asia, and Eastern and Central Africa the effects might be slightly negative, while in Southern Africa the productivity will remain approximately the same. It could be said that the effects on millet crop productivity will not be very severe for the first half of the 21st century, but they will be in Ghana in the 2080s.

Figure 48 Predicted yield variation in cassava under climate change effects in Asia and Africa according to Lobell et al. (2008), Mohamed (2002) and Butt et al. (2005).

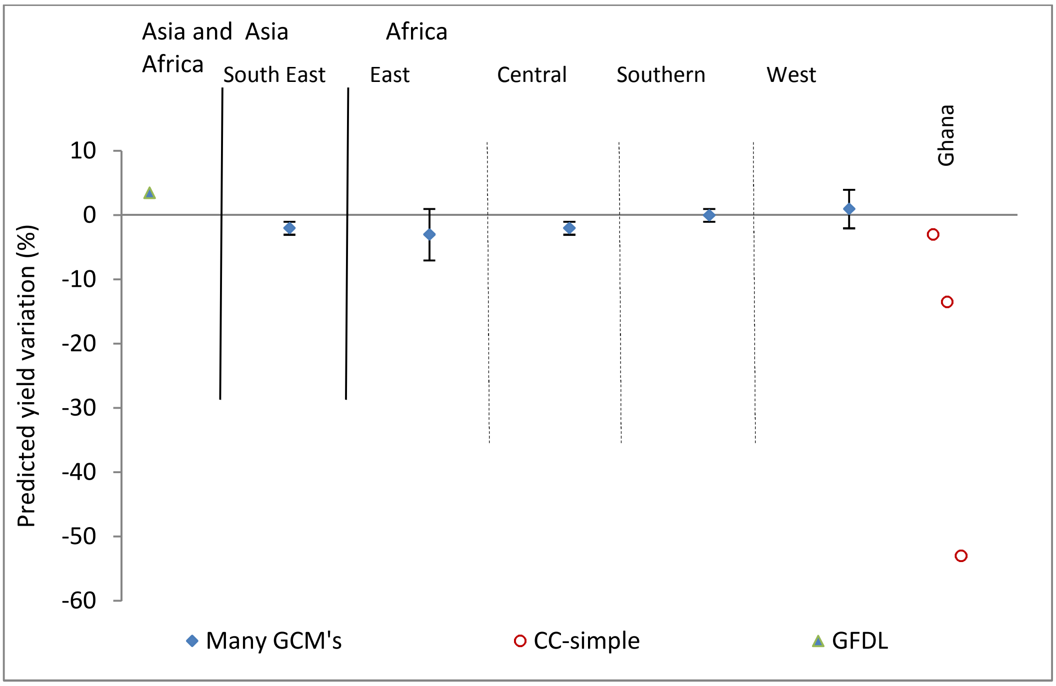


4.3.6.3 *Results by time slice*

Insufficient data for analysis.

4.3.6.4 *Results by climate change methodology (CC-simple and CC-complex)*

Figure 49 Predicted yield variation for cassava under climate change effects estimated with CC-complex and C-simple methods.



4.3.6.5 Results by climate change methodology (CC-simple)

Insufficient data for analysis.

4.3.6.6 Results by climate change methodology (CC-complex)

Insufficient data for analysis.

4.3.7 Sugarcane

4.3.7.1 Data sources

For this review, evidence on the impacts of climate change on sugarcane productivity in Asia was drawn from 2 peer review papers. Similarly, for Africa, 2 papers were analysed with data extracted from 2 journals (Table 15). Whilst the study by Lobell et al. (2008) is a global scale assessment, the other publications focus on sugarcane productivity in India and Swaziland. A summary of the published sources for each sub-region in Asia and Africa is given in Figure 50.

Table 15 Summary of literature included in the review for sugarcane in S. Asia and Africa.

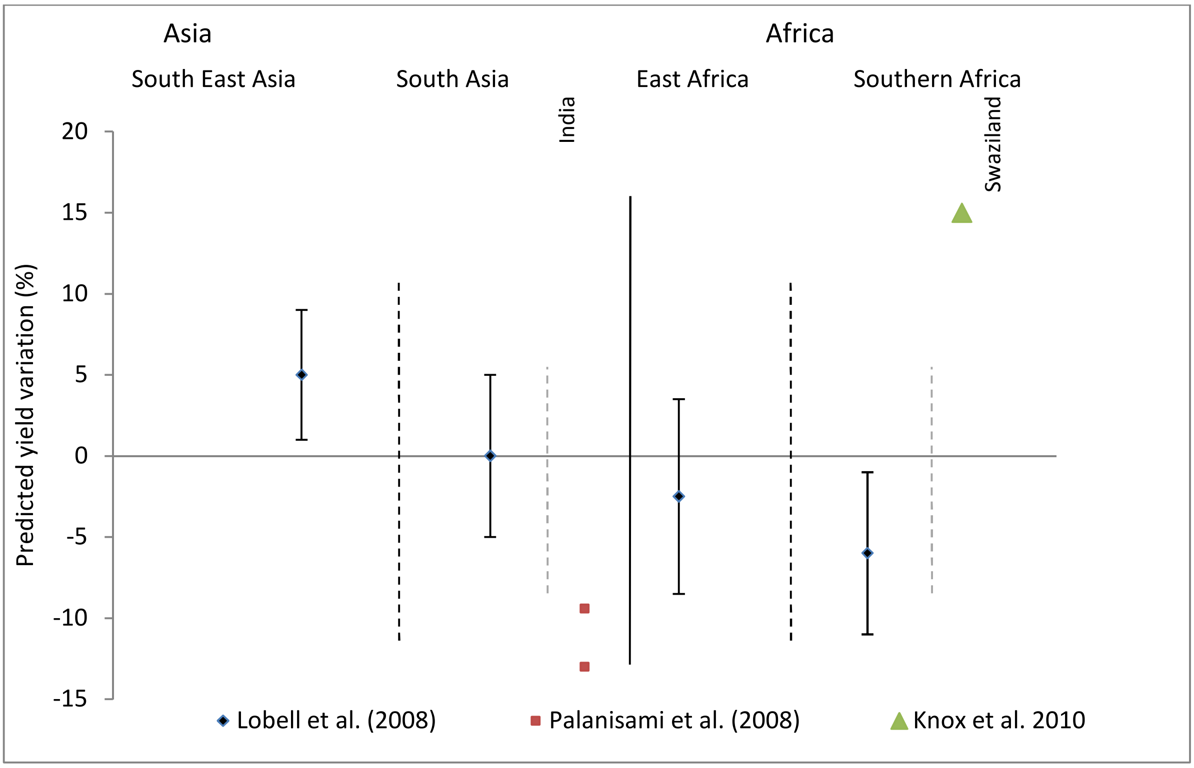
Author and year	Country/region	Journal title/report
ASIA		
Lobell et al. (2008)	Global	Science
Palanisami et al (2008)	India	
AFRICA		
Lobell et al (2008)	Global	Science
Knox et. al (2010)	Swaziland	Agricultural Systems

Figure 50 Number of published data sources used for assessing climate change impacts on sugarcane in Africa and Asia.

4.3.7.2 Overall results

Figure 51 shows the results of the studies for the future periods 2020s, 2030s and 2050s. The predictions for Indian sugarcane yield variation for the 2020s and 2050s were estimated using the GCM HadCM3 (Palanisami et al., 2008). The predictions for Swaziland are the result of the study of irrigation requirements by year 2050 (Knox et al., 2010). Lobell et al. (2008) predicts positive effects on sugarcane productivity for the 2030s in South East Asia and negative in Southern Africa. The range of values that the variability could take in South Asia and East Africa are positive and negative according to this study. However, in India the predicted yield variation in the 2020s and 2050s is negative (-13% and -9%), being more severe in 2020 than in 2050 (Palanisami et al., 2008). The study by Knox et al. (2010) predicts an increase in sugarcane crop yield in Swaziland for an increase in irrigation requirements in the 2050s.

Figure 51 Reported variation in sugarcane yield with climate change in Asia and Africa for all observations.

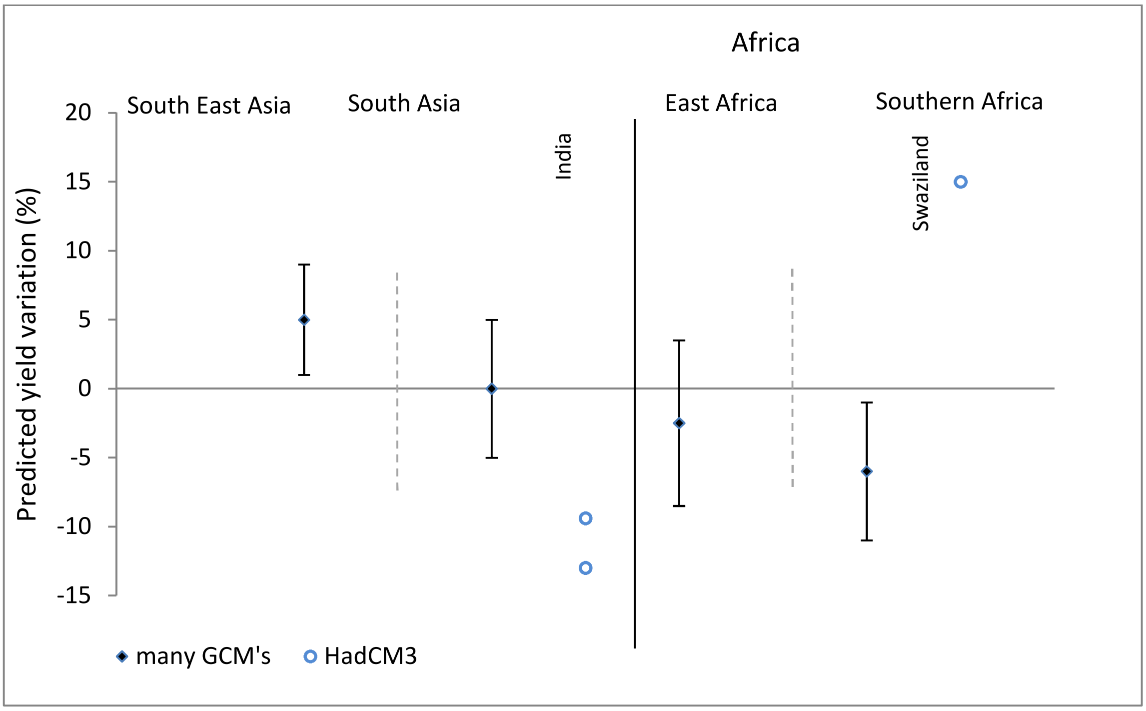


4.3.7.3 Results by time slice

Insufficient data for analysis

4.3.7.4 Results by climate change methodology (CC-simple and CC-complex)

Figure 52 Projected yield variation in sugarcane with climate change in S. Asia and Africa using CC-simple and CC-complex modelling methods.



4.3.7.5 Results by climate change methodology (CC-simple)

Insufficient data for analysis.

4.3.7.6 Results by climate change methodology (CC-complex)

Insufficient data for analysis.

4.3.8 Yams

4.3.8.1 Data sources

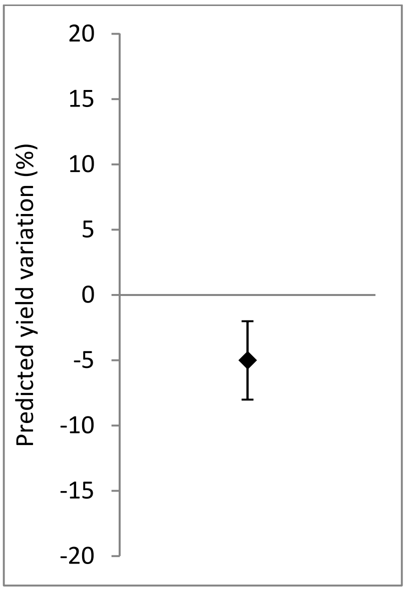
For this review, evidence on the impacts of climate change on yam productivity in Africa was drawn from 1 peer review paper. No evidence was found for S. Asia. This data is for Western Africa and drawn from research by Lobell et al (2008).

Author and year	Country/region	Journal title/report
AFRICA		
Lobell et al (2008)	Global	Science

4.3.8.2 Overall results

According to this probabilistic study, the effects of climate change in the 2030s will be negative for yam productivity in Western Africa (Lobell et al., 2008).

Figure 53 Projected yam yield variation under climate change in W Africa, based on Lobell et al. (2008).



4.3.8.3 Results by time slice

Insufficient data for analysis.

4.3.8.4 Results by climate change methodology (CC-simple)

Insufficient data for analysis.

4.3.8.5 Results by climate change methodology (CC-complex)

Insufficient data for analysis.

5 Synthesis

5.1 By crop

Rice

Unsurprisingly, most of the studies reported on rice focus on Asia. There is no common pattern to the trend of the predictions, with positive to negative forecasts in the ratio of 2:3. Most of the studies suggest small variations. For the predictions on a country by country basis, the results are sensitive to the study area and methodology used, and the effects being predicted.

In Bhutan the forecast is positive for the 2020s and 2050s (up to 10% increase), but not for the 2080s (-4%). For Bangladesh they are negative according to different studies in different time slices. They vary from -5% (2020s) to -10% (2080s). However, some studies based on fixed scenarios give positive variations when considering only temperature increases (up to 20%). In India there are estimations of up to 27% (main season rice) as well as reductions in yield productivity over by 40% by the 2080s, depending on the location of the study area. However, yield reduction is estimated to increase with time. In Sri Lanka the effects of climate change have produced positive variation on rice yield productivity by up to 10%. In Pakistan productivity is expected to be reduced by half by the 2080s.

The predictions for African rice are both positive (Eastern, Central and Western Africa) as well as negative, depending on the region, but they don’t exceed ±10%.

Wheat

A similar number of studies for Africa and Asia have been reported. Most of the predictions are negative for both continents. The forecast yield variation for large areas in the 2030s is generally negative but rarely exceeds 10%, excluding Southern Africa, where variability in wheat productivity could be up to 20%. General predictions for the 2050s forecast a higher decrease especially in Western Africa (up to 100%), Central Africa (80%), Eastern Africa and South East Asia (about 60%). Less severe effects were estimated for Northern Africa (less than 20% decrease).

In Bangladesh productivity is expected to be reduced in the 2050s as well as in other periods. In Tunisia the forecast is positive for the 2050s, but varies for the 2080s according to the region studied (e.g. an increase in Kairouan of 6-26% and a decrease in Jendouba of 18-25%). Libya and Morocco are expected to suffer a variation in wheat productivity of 10-20% in the 2050s, and Tunisia, Algeria and Egypt an increase of up to 15%. However, other studies predict a negative impact in Egypt. In India the projections vary depending on the region and methodology used to estimate climatic conditions; but some are negative and some positive depending on the study.

Maize

Most of the published studies regarding climate change on maize productivity focus in the African continent. Most predictions for Asia are negative. General predictions for South East Asia for the 2030s forecast a small variability in yield production that could lead to positive or negative effects on maize yield, which will not exceed 10%. For the 2050s the effects are expected to be positive (up to 10%). The same studies regarding the South Asian region predict negative effects that increase with time (-10% to -40%).

In India maize yield productivity is expected decrease. In general, winter maize has shown to be more vulnerable to climate change than monsoon wheat. The most severe consequences are forecasted to be on winter maize in the MIGP and will worsen with time (from -25% in the 2020s up to -60% in the 2080s). Nevertheless, monsoon maize productivity is expected to remain stable without significant variation.

The general trend on African maize production appears to be negative. For the 2030s the predicted variation was slightly negative (up to 5%) for East, Central, West Africa and the Sahel. The most severe effect was forecasted to take place in Southern Africa (-27%). For the 2050s predictions are slightly positive (up to 5%) in Eastern and Central Africa, and slightly negative in Western Africa. The highest decrease in production was predicted for Southern Africa (-44%) and the highest increase was for Northern Africa (53%).

In Kenya in the 2020s, the effect will be positive (up to 30%). In Cameroon, it is expected to increase by 15% in the 2020s, and decrease in the 2030s (20%) and 2080s. Studies made to predict yield variation in the 2050s forecast negative variation (up to -30%) for most countries, except for Somalia (+1.9%), Côte d'Ivoire (+1.6%), Lesotho (+26%), and Morocco (+73.5%). In Zimbabwe, depending on the study, planting data and area, the yield variation can be forecasted from -100% until over 100%.

Sorghum

Effects of climate change on sorghum appear to be negative when studying specific countries and around zero with the possibility of having positive and negative effects when regarding larger areas, with exception of the Sahel, where yield variation is forecast to be negative.

In India in the 2020s, yield could be reduced by 3% (SCZ) and by 14% (SWZ and CZ). In the 2050s the predicted variation is between -11% and -32% for the 2080s. Sorghum yield variations predicted for the 2030s are slightly negative in Sahel and Central Africa (less than 10%) and around zero with a high uncertainty for South Asia, Eastern, Southern and Western Africa. In Botswana in the 2050s, sorghum yield is forecast to be reduced by 10% in the Hard Veldt Region and 31% in the Sand Veldt Region. In Cameroon, the productivity is forecasted to be reduced by 40% in the 2080's. In Mali, there is expected to be a reduction in productivity of 11-17%.

Millet

Future changes in millet productivity have been studied more extensively for African regions than for South Asia. However, the predicted effects are reported to be both negative and positive when no adaptation measures are taken, again depending on the study area. In the 2030s millet yield could increase or reduce by about 10% in South Asia, and increase up to 8% in the Sahel. In Western Africa it might increase by up to 4% or decrease by 1%, while in the Central African region it is predicted to reduce by up to 20%. In Mali, the effects are expected to cause a reduction in productivity from 6% to 11%. In Niger by the 2020s, the yield decrease could range from 11% to 26%.

Cassava

Cassava's future productivity estimations are mostly estimated for African regions. The predictions for the 2030's for South East Asia, Eastern, Central and Southern are of negative small impacts (less than 10%) with some chances of becoming zero or positive. Positive effects on cassava's productivity are expected to occur in Western Africa (up to 4%). In Ghana, cassava yield productivity is expected to be reduced by 3%, 13% and 53% in the 2020's, 2050's and 2080's.However, it is forecasted, that the productivity in Asia and Africa rises by 3.5% by 2050.

Sugarcane

Sugarcane yield variation estimated for the 2030s show small positive effects in South East Asia (up to 9%) and positive or negative effects in South Asia (not higher than 5%). The predictions for Eastern and Southern Africa are slightly negative (less than 10%). In India, sugarcane productivity could decrease in the 2020s by 13% and by 9% in the 2050s.In Swaziland for the 2050s the yield is projected to increase by 15% assuming crop water requirements are satisfied.

5.2 By region

South Asia

The studies made regarding crop yield variation in South Asia show a general negative trend, especially on maize and sorghum in India and reduction expected on rice yield in Nepal, but increase in Sri Lanka. During the 2020s the most affected crop in this region seems to be maize, especially monsoon maize in the SP (-21%) and winter maize in the MIGP (-25%). Sorghum, sugarcane and rice will decrease by up to 13% in India and rice productivity by 2% in Nepal. In Pakistan and Sri Lanka rice yield will increase by 7% and 1%, respectively. Estimations for the 2030s forecast negative variation (up to 12%) for maize, wheat, millet, rice, sugarcane, and sorghum with a range of uncertainties which show the chance of increasing up to 8% (wheat) or 4% (millet). In Sri Lanka the effects of climate change appear to be positive on rice productivity (+6.6%). The predictions for the 2050s are negative for maize and wheat when considering the whole area (-40%). In India the climate change impacts on sugarcane, rice, sorghum and maize are negative, having the greatest impact on winter maize in the MIGP (-50%). However, in Sri Lanka and Pakistan, the rice productivity might be positively affected rising by 6 and 7.5%, respectively. In the 2080s, the consequences of climate change would be similar to the ones predicted for the 2050s, but more extreme. Indian sorghum and rice crop productivity would be reduced by 32 and 42%, respectively, and the worst prediction is be for winter wheat in the MIGP (-60%). Rice in Nepal would also be reduced (up to 39%). Pakistan (+7.5%) and Sri Lanka (+6 and +28%) are expected to benefit form the projected changes.

Other studies with no specified time slice predict an increase of up to 37% in wheat productivity in NW India, depending on the cultivar and a reduction of about 40% when ignoring CO_2 effects. The most favourable predictions were for cultivar WH542 in Hisar. Main season rice productivity might be positively affected (+27%) while second season is predicted to be reduced (-38%). Sorghum is forecast to reduce by up to 13% under rain-fed and no-stress conditions. In Pakistan, the predictions for wheat are negative (up to -31% and higher when CO_2 fertilisation is ignored). However, the uncertainty is high, with a potential positive (up to 30%) forecast also reported.

South East Asia

The predictions for the 2020s in South East Asia are slightly negative for rice in Bangladesh (up to -7%) and in Bhutan rice productivity could have some variation around current levels (±2%). General forecasts for the region predict a positive effect on sugarcane (up to +9%), and a small negative variation for cassava, wheat, rice, and maize, the latter being the worst (-7%). The 2050s climate conditions will affect wheat productivity most, on average halving yield in the region or by -32% in Bangladesh. Rice production will also be reduced in Bangladesh (-8%) but increased in Bhutan. Forecasted variations for the 2080s give general negative impacts on rice yield in Bangladesh (up to -14%) and in Bhutan (up to -12%) with some chances of an increase (+2%). Other studies predict positive effects on rice productivity in Bangladesh (up to +20%) and wheat variability but with a higher chance of it being negative (up to -15%) than positive (+5%).

East Africa

In the 2020s East African maize will benefit from climate change in central (+30% productivity) and west Kenya. In southern and eastern Kenya maize yield is forecast to reduce by 2% and 12%, respectively. In the 2030s, rice productivity is predicted to rice by up to 11%, while sugarcane, wheat and cassava are all expected to experience reduced yields by up to 10%. Maize might be favoured by climate change. Kenyan maize productivity is predicted to be reduced in the southern regions. Wheat is expected to decrease by up to 60% in the 2050s and maize increase from 1 to 9% in the Eastern region. However, in Kenya maize productivity is forecast to increase in the Central (+100%) and Western (+20%) area of the country, while it may decrease by around 40% in the Southern and Eastern areas.

Central Africa

Forecasts for Cameroon by the 2020s predict positive effects on maize (up to 25%) and negative on sorghum (-7%). The predictions for this region by the 2030s are slightly negative for sorghum, wheat, cassava, yam and maize, having the worst forecast millet productivity (up to -21%). Wheat productivity is predicted to decrease by 80% in Western Africa in the 2050s, while average maize productivity will remain stable. In Cameroon, Central African Republic, Chad, DR Congo, Congo, Gabon and Tanzania, maize productivity is forecast to reduced by between 10 and 20%. Estimations of Cameroon crop variation are negative for sorghum (-40%) and for maize (up to 15%) by the 2080s. In case of a temperature increase of 2ºC and rain decrease of 20%, maize productivity will decrease by 11-14%.

West Africa

Predictions for the 2020s show a negative effect on cassava in Ghana (-3%) and on millet in Niger for several scenarios by up to -26%. Small variation is predicted for the 2030s, being rice the most affected crop (-8%). Wheat productivity is predicted to decrease by 99% in Western Africa in the 2080s, while maize productivity will have a smaller response to climate change, with productivity reduced by 1 to 7%. Maize productivity is forecast to slightly increase (1.6%) in Côte d'Ivoire, and decrease in Liberia and Mauritania (-1.5%). Reductions of 15-30% are expected in Benin, Burkina Faso, Equatorial Guinea, Gambia, Ghana, Guinea, Guinea-Bissau, Liberia, Mali, Mauritania, Niger, Nigeria, Senegal, Sierra Leone, and Togo. Cassava production is forecast to reduce by 13% in Ghana. Cassava productivity in Ghana is estimated to decrease by the 2080s by about 53%. Other studies predict a yield decrease in West African sorghum (11-17%), millet (6-11%), and maize (11-13%).

Southern Africa

Studies show that the effects of climate change by the 2030s on Southern African crop productivity will be negative, except for rice (+8%). Most affected crops will be maize (-35%) and wheat (-22%). South African maize could be reduced by 8%. Predictions for the 2050s for Southern Africa forecast halving maize and wheat productivity. Maize yield is expected to be reduced by 10-35% in Angola, Botswana, Madagascar, Malawi, Mozambique, Namibia, South Africa, Zambia and Zimbabwe, and increased by 26% in Lesotho. Sorghum in Botswana is forecasted to decrease by 10% and 36% in the Hard Veldt and the Sand Veldt Regions, respectively. In Swaziland sugarcane productivity is expected to increase by 15% if crop water requirements are satisfied. Different planting dates and scenarios resulted in a positive effect on maize productivity at early and mid planting dates in Gweru (+160% and +12-37%, respectively), and in Beit Bridge (up to 170%) at mid planting dates. Late planting was estimated to have severe negative impacts, reducing maize yield by 40-98%.

Northern Africa

By the 2030s, an increase of 50-56% in average maize productivity is forecast. By the 2050s average maize productivity in this region is expected to rise by about 50% but with wheat yields reduced by 10-14%. In Sudan, maize productivity might decrease by 17%. The forecast variation in the Mediterranean coastal countries (Algeria, Tunisia, Libya, and Egypt) is predicted to decrease by 5-10% for 2031-2060. In Morocco, a study shows a positive impact (+70%) for the 2050s, while another reports a reduction of 10%. Climate change effects on wheat productivity in the 2050s are reported to be positive in Algeria, Tunisia and Egypt (4-11%) and negative in Morocco and Libya (-14%). In Tunisia, two positive and negative effects are expected in wheat productivity between 2071 and 2100. In Kairona, yield is forecast to increase (by 6-26%) and in Jendouba to decrease (by 17-25%).

Sahel

By the 2030s, a reduction in rice, maize and wheat (up to 10%) is reported, and a positive response for millet productivity (+8%).

6 Review limitations

The systematic review had a number of methodological limitations which need to be recognised:

1. **Access to published literature.** Some papers identified in the searches were not available (e.g. Tingem et al., 2008; Das et al., 2007; Geethalasksmi et al., 2008). It was also difficult to source some conference papers (e.g. Mohandass and Ranganathan, 1997). In these instances, the results were extracted from the abstract, where feasible.
2. **Crop model validation studies**. Many of the papers found in the systematic review were actually studies to assess the suitability of specific crop growth models to predict yield response under future conditions, rather than climate change impact studies *per se.*
3. **Lack of detail and confounding impacts.** Many articles and reports identified in the review were simply too general to extract useful data, whilst others provided vague results and confounding discussion.
4. **Difficulties in directly comparing results**. Each study included in the review focused on a different location, area, region, country or a continent, a unique approach to modelling yield (specific crop model) and differing approaches to assessing climate change (different GCMs, different downscaling approaches etc). This made direct comparisons between studies extremely difficult, with the results highly influenced by these 'effect modifiers'.
5. **Differences in reporting data.** The most frequent and useful results were those expressed as a yield variation in percentage. However, some studies gave predictions as yield variation in t ha^{-1} $year^{-1}$ (e.g. Schulze et al., 1993) or as yield deficit index (e.g. Lhomme et al., 2009) and thus had to be converted to percentage yield variation. Studies considering the economic aspects of climate change effects on agriculture predicted the impacts as a revenue variation (e.g. Gbetibouo and Hassan, 2005). Some studies presented their outputs as maps (e.g. Thornton et al., 2009, and Schulze et al., 1993). These are useful for understanding spatial impacts of climate change but difficult to extract specific representative values for particular regions and/or countries.
6. **Differences in modelling approach**. The reported differences in yield variation depend largely on the methodology adopted. For example, in many studies that used several GCM's the results were slightly different (e.g. Muchena and Iglesisas, 1995 or Modandass et al., 1997). Matthews et al. (1997) demonstrated that different crop models can also predict different yields under climate change conditions. These difference could therefore be a consequence of the model parameterisation rather the than impact of a changing climate.
7. **Regional differences.** It was noted that even within the same country differences in the effects of climate change can be very significant depending on location and crop type (e.g. Thornton et al., 2009, and Mati, 2000). It is thus difficult to compare the predictions for a catchment with the forecast yield variation in a larger region. The difference in the results will be highly dependent on the assumptions made and on the methodology adopted.

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9 Appendices

9.1 Crop production and revenue statistics

Table 16 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 ($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 17 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 ($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**

9.2 Countries by region

Table 18 Summary countries included in systematic aggregated by region (S Asia and Africa).

S Asia	**South Asia**	India	Pakistan
		Nepal	Sri Lanka
	South East Asia	Bangladesh	
		Bhutan	
Africa	**Central Africa**	Central African Rep	
		Congo	
		DR Congo	
		Equatorial Guinea	
		Gabon	
	East Africa	Burundi	
		Kenya	
		Rwanda	
		Tanzania	
		Uganda	
	North Africa	Algeria	
		Egypt	
		Libya	
		Morocco	
		Tunisia	
	Sahel	Burkina Faso	Mauritania
		Chad	Niger
		Eritrea	Senegal
		Ethiopia	Somalia
		Mali	Sudan
	Southern Africa	Angola	Namibia
		Botswana	South Africa
		Lesotho	Swaziland
		Madagascar	Zambia
		Malawi	Zimbabwe
		Mozambique	
	West Africa	Benin	Guinea-Bissau
		Cameroon	Liberia
		Côte d'Ivoire	Nigeria
		Gambia	Sierra Leone
		Ghana	Togo
		Guinea	