The Republic of Uganda

MINISTRY OF WATER AND ENVIRONMENT

CLIMATE CHANGE DEPARTMENT

Economic Assessment of the Impacts of Climate Change in Uganda

National Level Assessment:

Agricultural Sector report

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This document has been prepared by the Baastel consortium, composed of:

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EXECUTIVE SUMMARY

The agricultural sector is a fundamental part of the Ugandan economy, employing about 66 percent of the working population in 2009/10 and contributing about 22 percent to total GDP in the year 2012 (UBOS, 2013). Therefore, improving understanding of the nature and potential impacts of climate change on the sector is an essential prerequisite to the assessment and prioritization of adaptation actions.

Climate change can potentially impact agricultural production in a number of ways. In the case of crops this may be by changing: (i) the area suitable for agriculture, (ii) the length of the growing season, (iii) yield potential, (iv) the frequency and severity of extreme events (in particular droughts and floods) and (v) the incidence of plant diseases. In the case of livestock climate change may affect production through: (i) impacts on the quantity and quality of feed, (ii) increasing heat stress, (iii) changes to and spread of livestock diseases and (iv) changes in water availability (World Bank, 2013).

This report has assessed the potential economic impacts of climate change and finds that, in the absence of additional measures to adapt to climate change, there will be consequences in three areas: on food crops and livestock, on export crops, and on both of these sectors from extreme events.

Food crops: Climate impacts on regular farming are hard to predict. The very sophisticated models used for this purpose show wide divergence on what will happen to the output of 11 staples that have been modelled (cassava, groundnuts, maize, millet, pigeon peas, potatoes, rice, sorghum, soybean, sugar cane and sweet potato). Most of them indicate some decline up to 2050 but some even point to a possible increase. The largest falls are predicted for cassava, potato and sweet potato, which could decline by as much as 40% by 2050. In most cases, however, the decline in yields is less than 10%. **Under the scenarios considered overall losses for food crops by 2050 are not likely to be more than US$1.5 billion and could well be less than that. Under the assumed growth in the economy this would be less than 0.2 percent of GDP in that year.** It is important to note, however, that these national figures, mask important local differences in yields and value of production. In the regional analysis the largest impacts on production and total value are shown in the East and North for all crops.

<u>Estimated impacts on Livestock products production</u> are quite small in all cases (1 or 2 percent) based on the IFPRI modelling results. However, this modelling is only for yield and area whereas the key impacts on livestock will come from other climate change factors, in particular droughts, floods and diseases. Those estimates must therefore be interpreted carefully.

<u>Agricultural exports</u> are a key area of concern. Significant impacts on the Arabica coffee growing area to 2050 are predicted due to climate change. These will have major implications for production and export value particularly in the Eastern region. There are also significant impacts predicted in the Robusta coffee growing regions elsewhere although the research is much less developed than for Arabica coffee. Climate induced yield losses for coffee could be in the order of 50-75% by 2050, as a result of a combination of yield reductions and (more importantly) loss of areas where coffee can be grown. These would represent a major impact on the economy, which is currently deriving 18% of its export earnings from coffee. The value of losses due to a 50% reduction in production of Arabica and Robusta coffee combined, would be about US$1,235 million in 2050. The value of losses in a 75% reduction scenario would be about US$1850 million in 2050. Estimates of impacts on tea growing areas also indicate significant losses. Estimates consider a 50% fall in production by 2050 as plausible, which would result in a loss of about US$175 million in exports in 2050. Finally the IFPRI modelling shows some potential losses of cotton production due to yield impacts in the range of 60-77% of the no climate change scenario by 2050. Taken together these results indicate the potential for Ugandan agricultural export production and value to be strongly hit by climate change in the period to 2050 in the absence of adaptation actions.

Extreme events: It is widely accepted that extreme weather events have been increasing and becoming more severe in recent years and the analysis by Rautenbach (2014) concludes that these risks are likely to increase in the future in large parts of Uganda. To give an indication of the order of magnitude of current losses, these are estimated to be about US$470 million to food crops, cash crops and livestock as a whole, resulting from the 2010-11 drought (OPM (2012)). This equates to about 16 percent of the total value of these items in GDP for 2011. The annual damage figure of US$47million to crops from the 2008 drought (given in NEMA, 2008) is equal to approximately 3 per cent of the value of all cash and food crops. For some agricultural products **the threat from droughts and floods appears to be more important than the threat from decreased yields and therefore this thereat must be considered as a priority in terms of adaptation action**. It should also be stressed that current and future increased risks from flooding and droughts are in areas of existing poverty and therefore these events have serious consequences for local economies and food security.

Priorities for adaptation options: In the National Climate Change Costed Implementation Strategy, the Government of Uganda has identified eight strategic interventions for adaptation in the agricultural sector, with a proposed budget over the next 15 years of about US$297 million (MWE, 2012):

1. Promote and encourage highly adaptive and productive crop varieties and cultivars in drought-prone, flood-prone and rain-fed crop farming systems

2. Promote and encourage highly adaptive and productive livestock breeds

3. Promote and encourage conservation agriculture and ecologically compatible cropping systems to increase resilience to the impacts of climate change.

4. Promote sustainable management of rangelands and pastures through integrated rangeland management.

5. Promote irrigated agriculture by encouraging irrigation systems that use water sustainably

6. Promote and encourage agricultural diversification, and improved post-harvest handling, storage and value addition in order to mitigate rising climate related losses and to improve food security and household incomes.

7. Support community-based adaptation strategies through expanded extension services and improved systems for conveying timely climate information to rural populations for enhanced climate resilience of agricultural systems

8. Develop innovative insurance schemes (low-premium micro-insurance policies) and low-interest credit facilities to insure farmers against crop failure and livestock loss due to droughts, pests, floods and other weather-related events

A quantitative assessment of those interventions needs a bottom-up analysis of the costs and benefits, which has to work from the local level. Some examples of this will be undertaken in case studies implemented in the Karamoja and Mount Elgon region. It should be noted that further measures have been proposed for adaptation: for crop production by UNDP, for coffee and other export crops by USAID and Oxfam, and for extreme events by UNEP/UNDP.

The eight categories are evaluated qualitatively by using the results of the study to review how the measures, if implemented effectively, would: (i) contribute to alleviating particular negative impacts of climate change and variability, (ii) have a role in addressing the adaptation deficit, in mainstreaming adaptation. The actions are presented in the form of "adaptation signatures", indicating those that address current problems or early priorities and those that may be necessary in the medium term and longer term actions. Where relevant we also identify critical decision points in implementing these policies and measures.

The main points that emerge are:

A. In almost all cases the proposed measures deal with current climate variability and can be justified in economic terms on those grounds. Hence they are part of addressing the adaptation deficit and if implemented effectively should provide benefits irrespective of future climatic change.
B. Most of those adaptation actions that have medium to long term benefits need to be initiated now because it will take time to test pilot versions and develop programmes that are robust.
C. Evidence from the existing literature and from this study suggests that the benefits of many of the proposed measures are potentially high relative to the costs. This is true for example for items 1-3, 6 and 7 in Table 6.1. In the case of item 4 (sustainable management of rangelands and pastures) the benefits from a climate viewpoint are less studied. In the case of item 5 (irrigated agriculture) and item 8 (insurance schemes), studies point to the great importance to ensure that the environmental context is right and that the economic support takes account of issues relating to sustainability and affordability.
D. In terms of timing items 3-8 in Table 6.1 could yield some benefits in the short to medium term, making them more urgent in terms of implementation. Items 1-2 have a somewhat longer perspective.

Of course in no case is the evidence from other studies a guarantee that the implementation of the measures in Uganda will be successful and cost effective. The programme needs to be evaluated at the national level on a case by case basis and implementation has to be technically and economically efficient. However, what the table does provide is an indication that in most cases the elements in the programme are on the right course.

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LIST OF ACRONYMS

Acronym	Definition
CDKN	Climate & Development Knowledge Network
CNRM	Centre of National Meteorological Research
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DaLA	Damage, Loss and Needs Assessment
ECHAM	Climate model of the Max Planck Institute for Meteorology (Hamburg)
GDP	Gross Domestic Product
GoU	Government of Uganda
IMPACT	International Model for Policy Analysis of Agricultural Commodities and Trade
MIROC	Model for Interdisciplinary Research on Climate
MWE	Ministry of Water and Environment of Uganda
OPM	Office of the Prime Minister
UBOS	Uganda Bureau of Statistics
UCA	Uganda Census of Agriculture

1. INTRODUCTION

This report of the Economic Assessment of the Impacts of Climate Change in Uganda, prepared for the Ministry of Water and Environment of Uganda (MWE) and the Climate & Development Knowledge Network (CDKN) focuses on the agricultural sector. Climate change can potentially impact agricultural production in a number of ways. In the case of crops it may do so by changing: (i) the area suitable for agriculture, (ii) the length of the growing season, (iii) yield potential, (iv) the frequency and severity of extreme events (in particular droughts and floods) and (v) the incidence of plant diseases. In the case of livestock climate change may affect production through: (i) impacts on the quantity and quality of feeds, (ii) increasing heat stress, (iii) changes to and spread of livestock diseases and, (iv) changes in water availability (World Bank, 2013).

This report is structured as follows. Following this introduction, Section 2 provides an overall outline of the agricultural sector of Uganda underlining its importance to the economy as a whole and the relative contribution of different sub sectors to domestic and export production. In Section 3 a summary is given of the methodology and results of the assessment of impacts of climate change on food crops and livestock. This is mainly at the national level but with some analysis at the regional level. Section 4 summarises the assessment of impacts of climate change on agricultural exports with a key focus on coffee exports due to its importance as an export crop and major source of foreign exchange for the country, and the significant threat of climate change to the availability of suitable growing area. A discussion of impacts on agriculture of extreme weather events, in particular floods and droughts, is given in Section 5. Section 6 presents conclusions on the assessment of climate change impacts and discusses priorities for adaptation options.

Annexes 1 and 2 present further details of the methodology and results of the assessment summarised in Sections 3 and 4 of impacts of climate change on food crops and livestock, and on agricultural exports. Annex 3 summarises key issues in the economic assessment of agricultural vulnerability to climate change and reviews results of other studies of relevance to the Uganda assessment including those for other Sub Saharan Africa countries.

The assessments of economic impacts of climate change given in this draft report take a generally top down methodological approach in order to provide aggregate national and regional estimates of potential impacts on agricultural production and value. This is intended to inform the discussion on adaptation priorities but it does not cover in detail the important aspect of the consequences of climate change on the livelihoods of the population in areas most vulnerable to agricultural impacts. This aspect will be included in a subsequent draft when the results of the case studies are available. These, together with other existing studies on livelihood and food security impacts in Uganda, will give a more bottom up assessment to complement and link to the aggregate results given in this report.

This report was written by Nick Dale and Anil Markandya of Metroeconomica. We gratefully acknowledge the helpful comments and suggestions provided on initial results of the agricultural assessment by Government of Uganda officials during the mission to Uganda in September 2014.

2. OUTLINE OF THE UGANDA AGRICULTURAL SECTOR

The agricultural sector is a fundamental part of the Ugandan economy employing about 66 percent of the working population in 2009/10 (Statistical Appendix, 2013) and contributing about 22 percent to total GDP in the year 2012 (UBOS, 2013), although this percentage has been declining over recent years. Table 2.1 shows the contribution of the agricultural sub sectors to total GDP including food crops and cash crops largely for export.

Table 2.1: Contribution of Agricultural Sector to GDP (2012). [1]

	GDP at current prices (Bill. UGX)	GDP at current prices (million US$)[2]	Share of total GDP (%)
Total GDP at market prices	53,202	19,685	100
Agriculture, forestry and fishing:	11,789	4,362	22.2
Cash crops	869	322	1.6
Food crops	6,571	2,431	12.4
Livestock	1,001	370	1.9
Forestry	1,886	698	3.5
Fishing	1,461	541	2.7

Source: Assembled from data in UBOS 2013.

The Uganda Agricultural Census (UBOS, 2010) showed that 17 major food crops are grown in the country. These include: Cereals (Maize, Millet, Sorghum, Rice); Root crops (Cassava, Sweet potatoes, Irish potatoes); Pulses (Beans, Cow peas, Field peas, Pigeon peas); and Oil crops (Groundnuts, Soya beans, Simsim), Plantain Bananas (Food, Beer, Sweet types). The total area planted in 2012 for the above crops was about 5,700,000 Ha. Table 2.2 gives production estimates for 2012, indicating that maize, potatoes, cassava, and plantain/bananas are among the crops with the highest production quantities (UBOS, 2013). It should be noted that UBOS statistics on crop area and production in 2012 were projected based on the Uganda Census of Agriculture (UCA) of 2008/9.

Table 2.2: Production for selected food crops ('000 Tons), 2012

Crops	2012
Cereal	
Millet	244
Maize	2,734
Sorghum	336
Rice	212

[1] New GDP estimates rebased to 2009/10 including improved estimates of non monetary (subsistence) production were issued by UBOS (2014) as this report was being finalised. These show about a 30 percent increase in total value of the Agriculture, forestry and fishing sector in GDP. For 2012/13 the share of total GDP for the sector increased to about 25 percent partly accounted for by an increase in estimated livestock contribution to about 5 percent.

[2] Calculated with exchange rate of 1 UGX = US$0.00037 at Dec 2012.

Wheat	20
Root Crops	
Sweet Potato	1,852
Irish Potato	185
Cassava	2,807
Pulses	
Beans	870
Field Peas	12
Cow Peas	10
Pigeon Peas	13
Others	
Plantain Bananas(All types)	4,503
Groundnuts	295
Soya beans	23
Simsim	124
Sunflower	230

Source: UBOS (2013)

The main cash crops of Uganda are coffee, tea, cotton and tobacco. Coffee forms a major source of foreign exchange for the country since it dominates exports in terms of value (see Section 4). The agricultural sector contributed about 50 percent of the total export revenues in 2012.

Livestock production accounts for about 8 percent of the total agricultural sector GDP, with widespread rearing of cattle, sheep, goats, pigs and poultry. Holdings of livestock over recent years are shown in Table 2.3 (from UBOS, 2013). In 2011 the production of beef was 191,000 tonnes, goat meat and mutton 35,666 tonnes and pork 20,867 tonnes.

Table 2.3: Livestock numbers ('000 animals), 2009 – 2012.

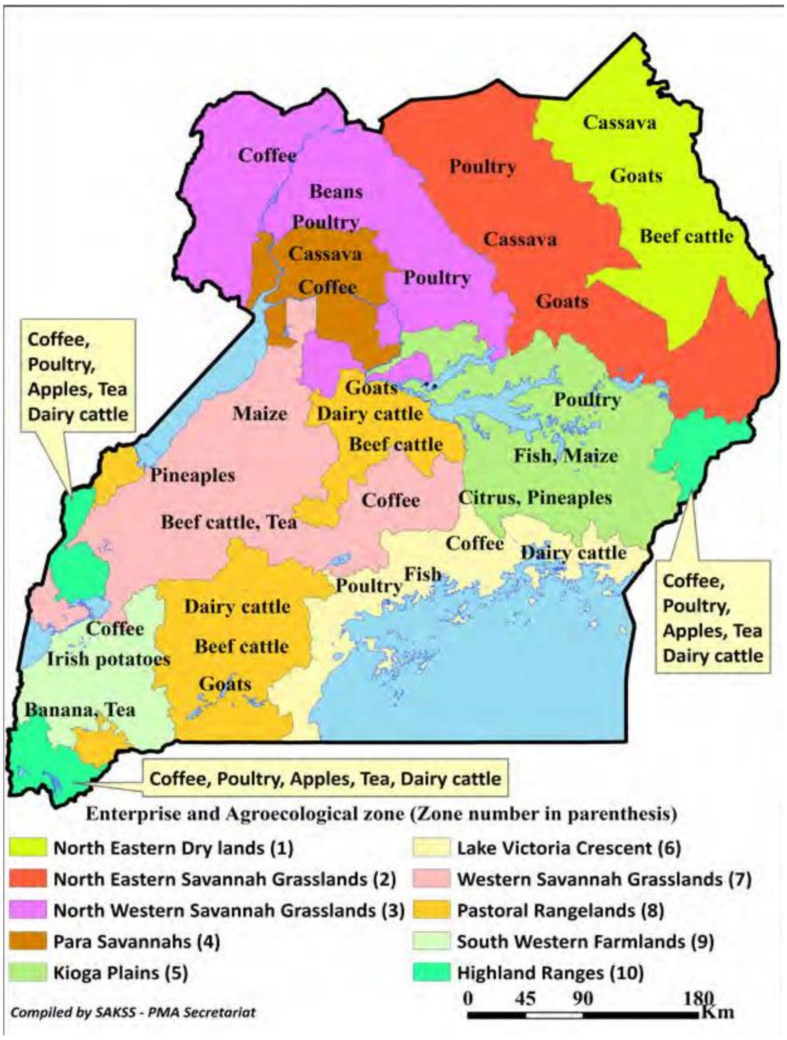
Species	2012
Cattle	12,541
Sheep	3,842
Goats	14,012
Pigs	3,584
Poultry	45,901

Source: UBOS (2013)

The Agriculture Sector Development Strategy and Investment Plan (MAIIF, 2010) defines 10 main agro-ecological zones in Uganda. Figure 2.1 provides an illustration of this zoning, including an indication of the key agricultural products in each zone.

Agricultural production in Uganda is mainly dominated by smallholder farmers engaged in food and cash crops, forestry, horticulture, fishing and livestock farming. Agriculture productivity of most crops has been declining overall in the last decade owing to a number of factors which include: high costs of inputs, poor production techniques, limited extension services, over dependency on rain-fed agriculture, limited markets, land tenure challenges and limited application of technology and innovation (NPA, 2013). A heavy dependence on rain-fed agriculture (with only about 0.1 per cent of production from irrigation) and natural resources means that production is particularly vulnerable to climate variability and increased intensity and frequency of natural hazards, with serious consequences for food security (GoU, 2007).

Figure 2.1: Agro-ecological Zones in Uganda



3. SUMMARY OF ASSESSMENT OF IMPACTS OF CLIMATE CHANGE ON FOOD CROPS AND LIVESTOCK

The overall aim of the economic assessment of impacts of climate change on food crops and livestock is to estimate possible future losses to these products and to their economic value as a result of climate change. The comparison is made between selected climate change scenarios and a no climate change scenario. The estimated value of losses can be expected to vary according to the different climate scenarios, as well as what is assumed about socio economic development and future prices. This approach therefore allows a comparison of the impacts on the agricultural sector of different scenarios and indicates if there are potentially significant losses for certain products.

As noted climate change can potentially impact agricultural production by: (i) reducing the area suitable for agriculture, (ii) altering the length of the growing season, (iii) reducing the yield potential, (iv) increasing the frequency and severity of extreme events (in particular droughts and floods) and (v) increasing the incidence of plant diseases (World Bank, 2013).

A literature review was carried out on available studies on these impacts in Uganda and in the wider region of Sub Saharan Africa (this is reported in detail in Annex 3). This showed that a number of research studies have analysed impacts on crop yields in Sub Saharan and East Africa including some for Uganda. Results are mostly available for key crops produced in Uganda, specifically maize, millet, sorghum, beans, rice and groundnuts. In most cases they show a large range of possible yield impacts. Climate change impacts on agricultural production other than on yield potential are less well reported in the reviewed studies. Changes in the area suitable for crops are covered to some extent and there is only limited detailed quantitative analysis on the impact on future production of extreme events (the available estimates are largely aggregate losses and not product specific (see Section 5 for a discussion of floods and droughts) and plant diseases. Much less research has been published on the effects of climate change on livestock than on crops and there are apparent inconsistencies in the findings of available studies (World Bank, 2013).

After considering the available research data it was decided to use the results of modelling of climate change impacts on agriculture in Uganda by the International Food Policy Research Institute's (IFPRI) as a key basis for the economic assessment of food crops and livestock for Uganda. This advantage of using the IFPRI datasets is that they: (i) cover a wide range of food crops and livestock, (ii) use a consistent methodology which allows direct comparison of impacts between specific products and (iii) include impacts on future production from changes in both yields and suitable cultivation area. The project team were also greatly assisted by being given access to unpublished and updated results from the IMPACT[3] modelling of climate change effects by IFPRI which allowed much more detailed assessment than would otherwise have been possible using ad hoc results for crops and livestock from a range of different studies. The IFPRI methodology is explained in greater detail in Annex 1.

Using datasets from the IFPRI modelling we have undertaken a national level analysis of impacts on key crops and products and also made some assessment of impacts at the regional level.

[3] IMPACT (International Model for Policy Analysis of Agricultural Commodities and Trade) is a partial equilibrium agricultural model for projecting global food supply, food demand, and food security (Waithaka et al.,2012)

3.1.1. National Level Analysis of Crops and Livestock

The national level analysis covers climate change impacts on production and value of 14 crop products and 6 livestock products in Uganda for which IMPACT data are available. Some perennial crops, notably bananas (matooke[4]) and coffee, are not included in the IMPACT data. Coffee is covered in detail in Section 4.

Results are available from the IMPACT modelling for impacts under both the CSIRO climate model and MIROC climate models[5]. For each model, projections are available for agricultural production under:

- Emissions scenarios A1B (higher emissions scenario), B1 (lower emissions scenario), and for a no climate change scenario (see Box 1).
- Global socio economic scenarios defined according to GDP and population growth (pessimistic, baseline and optimistic)[6].

A summary of crop production projections from IFPRI modelling for 11 Crops in 2050 for the scenarios explained above is given in Figure 3.1. The key comparison to note here is between production in the climate change scenarios for different models and the no climate change scenario (the right hand set of columns for each crop). Figure 3.2 presents production in the climate change scenarios as a percentage of production without climate change in 2050. For some crops there is clearly lower production under climate change scenarios than no climate change (e.g. around 60 percent for cassava and potato, and a little more than 60 percent for sweet potato). In other cases the difference is more marginal (e.g. millet, sorghum). In some cases, such as maize, whether production is lower or higher under CC depends on the model and scenario.

A summary of livestock product projections in 2050 for the scenarios given above is given in Figure 3.3. This shows that in all cases there are no significant differences between production in the climate change scenarios for different models and the no climate change scenario. This is an interesting finding in that it suggests that changes in overall trends in precipitation and temperature will not result in great impacts on the yield of livestock and that the key climate change impacts to focus on will be those from droughts and floods. This conclusion should, however, be treated with caution given the relative lack of clear results from other studies on this subject (see Annex 3). It does nevertheless concur to some extent with findings from Seo et al (2008) who suggest that warming is likely to increase livestock income in some other parts of Sub-Saharan Africa unless there are very large increases in temperature.

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[4] In Uganda, matooke is the fruit of a variety of starchy banana, commonly referred to as cooking bananas.

[5] CSIRO is the climate model developed at the Australia Commonwealth Scientific and Industrial Research Organisation; MIROC is the Model for Interdisciplinary Research on Climate, developed by the University of Tokyo Center for Climate System Research.

[6] Pessimistic, baseline and optimistic socio economic scenario projections to 2050 are explained further in Annex 1 (Table A1.1) and are taken from the IFPRI study by Waithaka, M. et al.(Eds) (2012)

Box 1: Greenhouse Gas Emissions Scenarios

Emissions scenarios used in the IMPACT modelling of agricultural production are from the Special Report on Emissions Scenarios (SRES) used in the modelling for the IPCC 3rd and 4th Assessment. The specific SRES scenarios used in the IMPACT modelling were:

- A1B which is a higher emissions scenario assuming fast economic growth, a population that peaks mid-century, and the development of new and efficient technologies, along with a balanced use of energy sources (Waithaka et al.,2012).
- B1 which is a lower emissions scenario assuming a population that peaks mid-century (like A1B), but with rapid changes toward a service and information economy, and the introduction of clean and resource-efficient technologies (Waithaka et al.,2012).

A new range of scenarios called Representative Concentration Pathways (RCPs) were introduced in the IPCC 5th Assessment Report (AR5) and have been used in the Regional-scale Climate Change Projections by Rautenbach (2014). The higher SRES emissions scenario A1B used in IFPRI modelling is closest to RCP6 and the lower SRES emissions scenario B1 used in IFPRI modelling is closest to RCP4.5. The more extreme higher emissions scenario RCP8.5 used in Rautenbach is closest to the AR4 emissions scenarios A1FI which has not been used in the IFPRI modelling. See Annex 1 for more details.

Figure 3.1: Overview of Crop Production Projections for 11 Crops (Total production in 2050, '1000 tonnes).

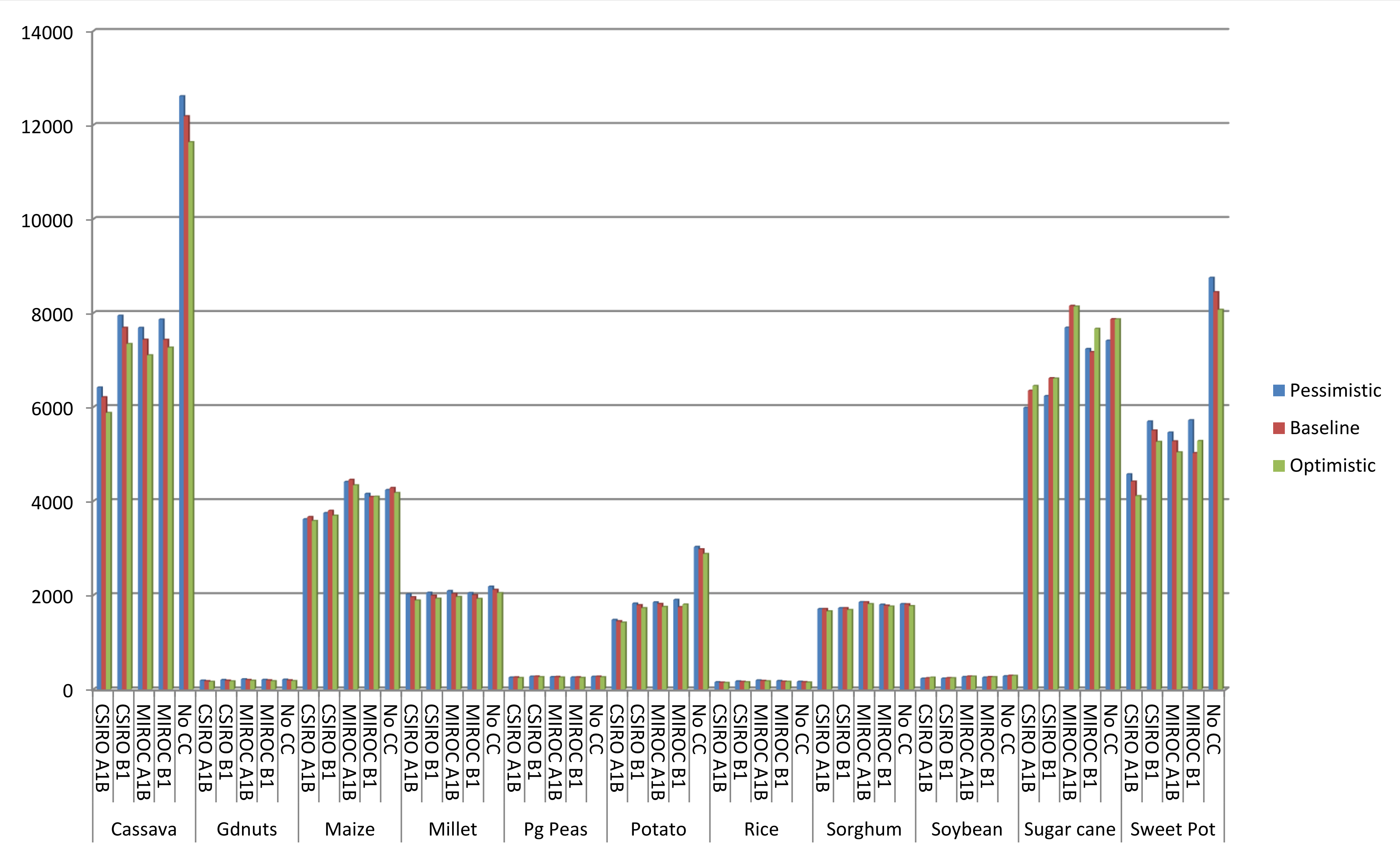


Figure 3.2: Production with climate change as a percentage of production without climate change in 2050 (%)

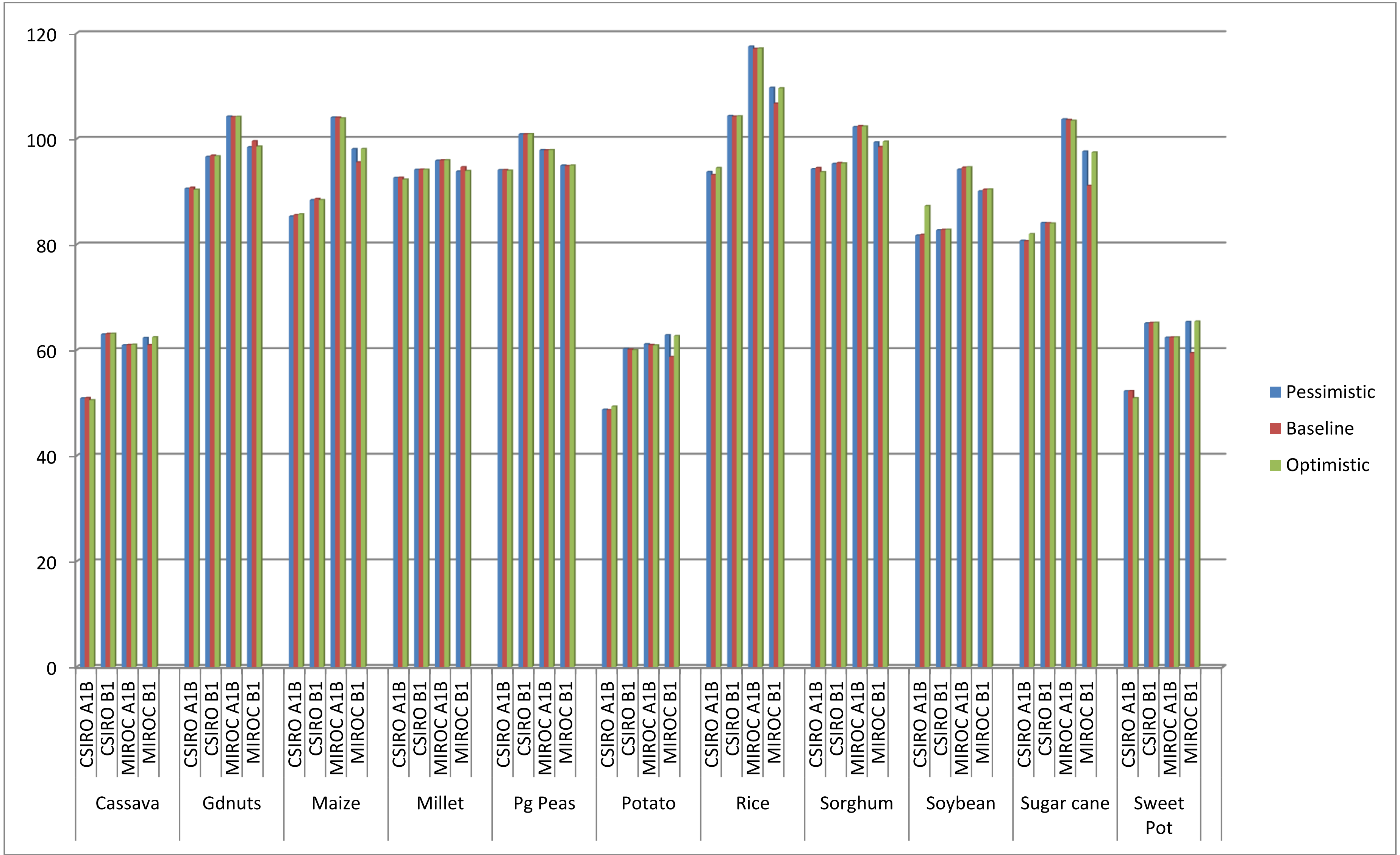
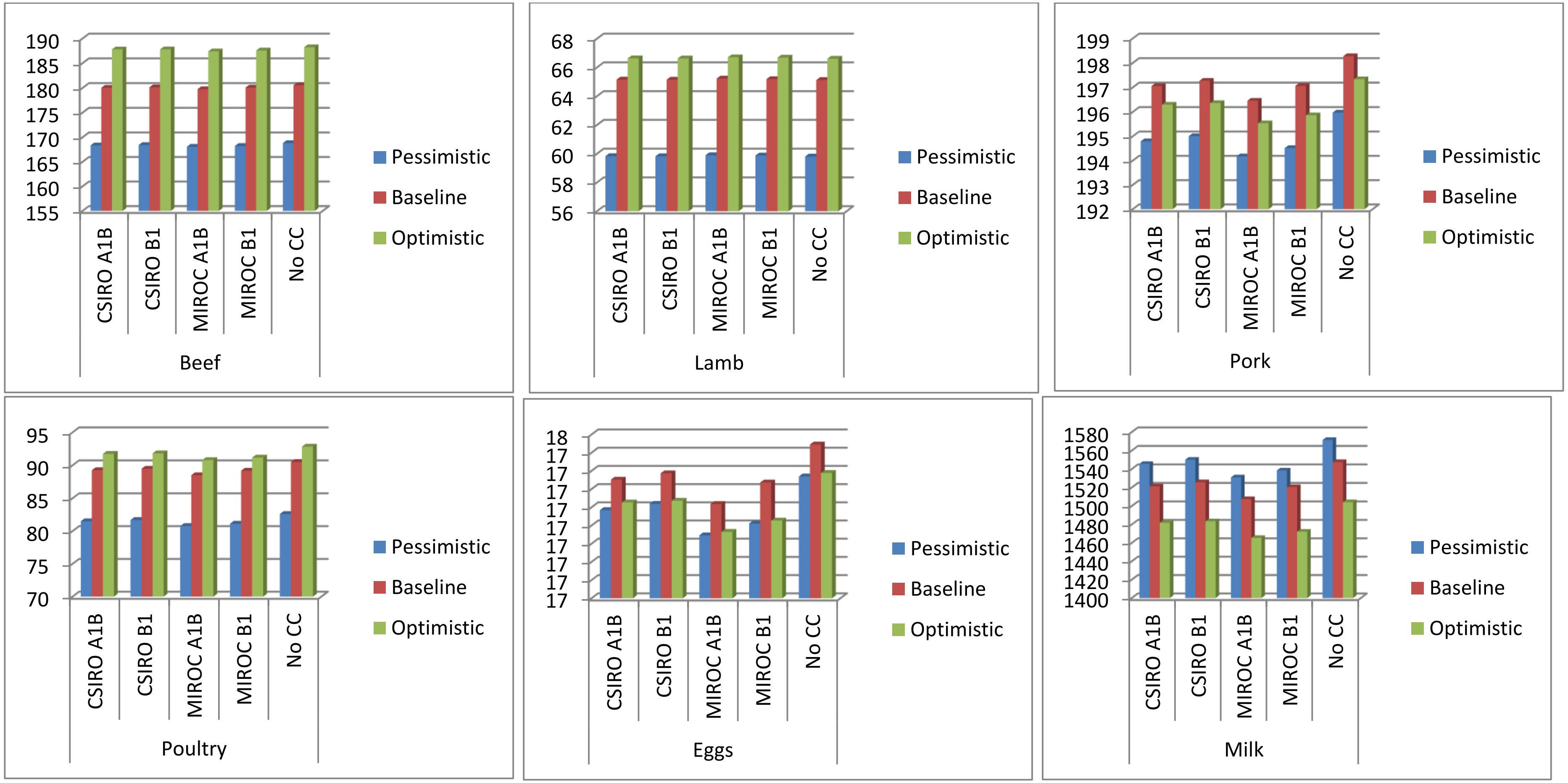


Figure 3.3: Overview of Livestock Production Projections (Total production in 2050, '1000 tonnes).



Based on: (i) the production estimates for each emission scenario and global socio economic scenario for each product summarised above and (ii) price data provided by IFPRI for each scenario and product, we have calculated the following:

1. Total value of production in 2050 for each product under each scenario. Figure 3.4 summarises these estimates for 11 crops by highlighting the difference in value between (i) climate change scenarios (climate model and global socio economic scenarios) for each product in 2050 and (ii) the no climate change scenario in 2050. Thus negative values beneath the x-axis represent a decrease in value under climate change and positive values above the x-axis represent an increase in value under climate change.

   It is noticeable that some crops clearly lose significant value under climate change scenarios to 2050 including sweet potato, potato and cassava. In other cases there are overall gains in value under climate change scenarios such as for maize and sorghum. And in other cases both gains and losses are estimated according to the climate model such as for sugar cane.

   It is important to bear in mind that the **estimates of value changes are very dependent on price projections** to 2050 modelled by IFPRI. For example, since production of maize is projected to be lower in 2050 under most climate change scenarios than without climate change (see Figure 3.1) the gains in value of maize shown in 2050 under climate change scenarios (Figure 3.4) are due to much higher projected prices for maize compared with prices without climate change.

   It should also be noted that a high percentage of crop production is not sold at market but consumed or stored. Therefore, the estimates of climate change impacts on value represent the change in total value of production at the projected prices whether sold or not. Total losses appear to be in the range of US$1.5 billion, which is around 8 percent of agricultural output in 2012. Of course the economy is expected to be much larger in 2050 and such losses would be less than 0.2 percent of projected GDP in that year.

2. Change in net income in 2050 for each product due to climate change scenarios. This is shown in Figure 3.5 and is based on the above estimates of difference in value between climate change scenarios for each product and the no climate change scenario. It was calculated using data on the typical percentages of gross margin in total revenue for each product.

   A significant caveat here is that these estimates are likely to overestimate real changes in the net income of farmers because (i) much of the production of food crops by farmers is for family and local consumption and is not sold and (ii) the international prices used in the estimates of net income changes may not be representative of the local market price for some crops.

Figure 3.4: Value Change due to Climate Change compared with no Climate Change in 2050 (USD million at 2000 prices).

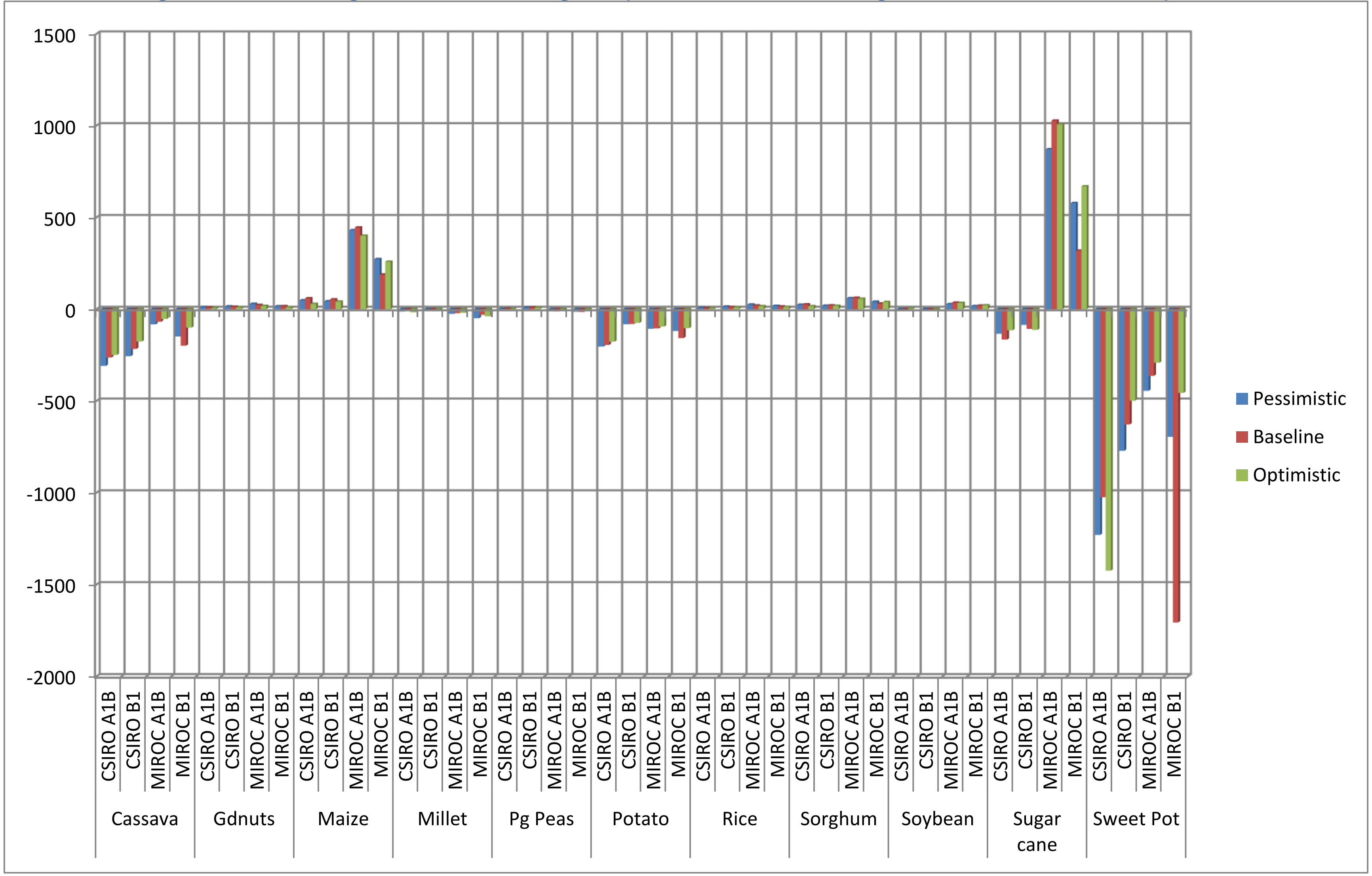
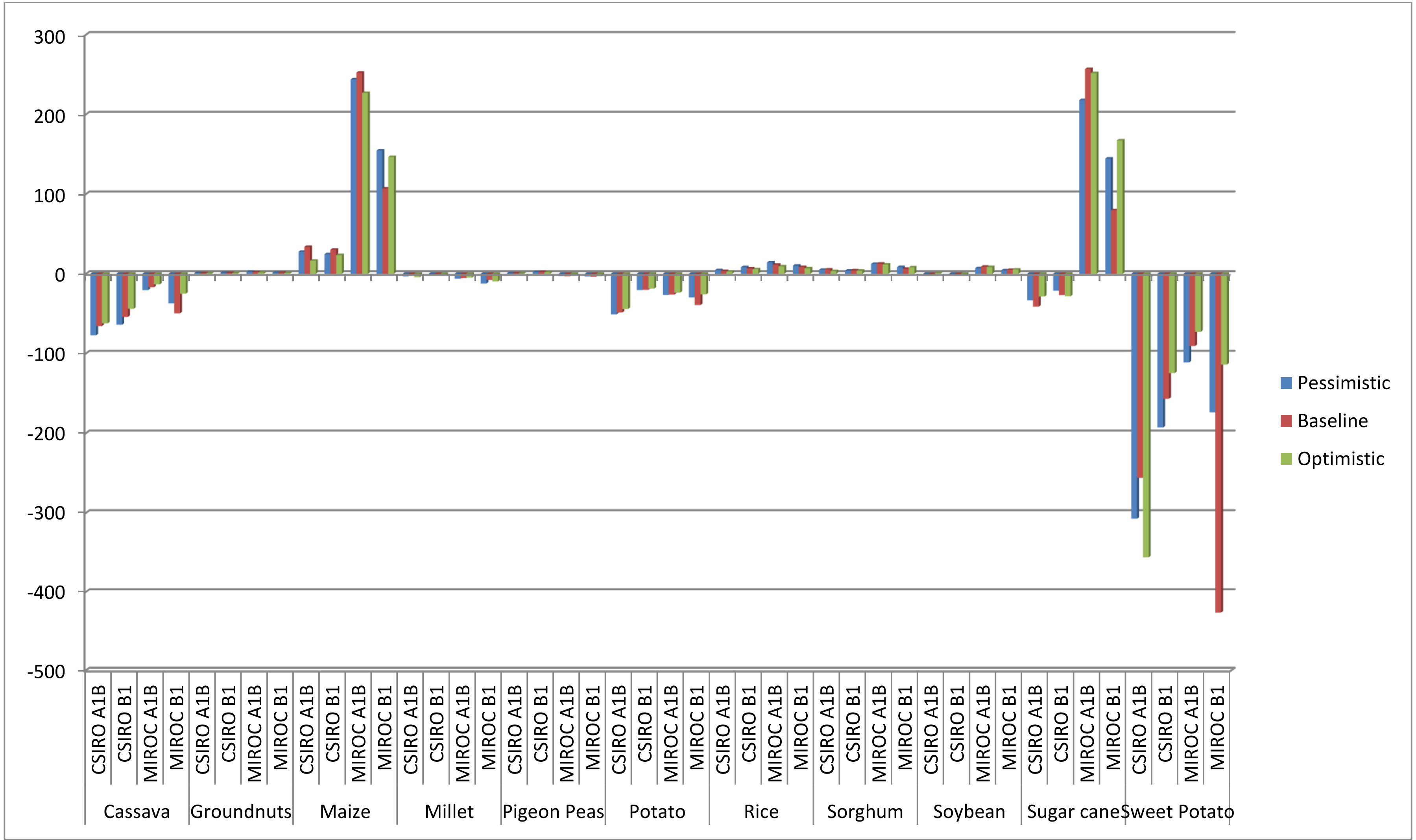


Figure 3.5: Change in net income due to Climate Change compared with no Climate Change in 2050 (USD million at 2000 prices).



Preliminary findings for the national level assessment of food crops and livestock are as follows:

- **Results for production and value changes show great divergence between different climate models.** There is no clear pattern between models in terms of significance of impacts. In some cases the CSIRO results show larger impacts on value (e.g. for Cassava) and in others the MIROC results show larger impacts on value (e.g. groundnuts). Some products show a consistent direction of change in value (e.g. potato, sorghum) but in some cases both positive and negative changes are given depending on the model and scenario (e.g. soybean).
- **Most of the modelled crops show reductions in total production under most climate change scenarios** compared with no climate change (e.g. cassava, maize, millet, groundnuts) but there are some cases where a model shows increases in production with climate change (e.g. MIROC A1 for maize).
- **For some crops the impacts on production of climate change in 2050 are quite significant in percentage terms** (e.g. cassava, potato and sweet potato show around 40 percent reductions under climate change scenarios). In most other cases, the percentage reduction is less than 10 percent (e.g. millet, sorghum and pigeon peas).
- **For livestock products impacts on production are quite small in all cases** (1 or 2%). Note that this modelling is only for yield whereas the key impacts on livestock may come from other factors (such as extreme weather events).
- **Results for value of changes in 2050 due to climate change do not show a consistent picture with both negative and positive changes in value depending on the crop and climate model** (e.g. soybean). For several crops (e.g. maize, sorghum and groundnuts) the results show an increase in value under climate change in 2050 even though total projected production in the climate change scenarios is generally lower than the no climate change scenario (except for MIROC A1). This is due to the projected prices in 2050 being much lower in the no CC scenario than the CC scenario (e.g. maize prices in the no climate change scenario are 10 to 50% below climate change scenario prices depending on the scenario).
- **Great caution is needed in interpreting impacts on value of production** due to the uncertainty inherent with projecting prices to 2050. Nevertheless it is instructive that overall losses in 2050 are projected to be no more than US$1.5 billion, which would be less than 0.2 percent of GDP in that year.
- **This national level analysis is useful for highlighting which food crops are most vulnerable** to climate change impacts and the order of magnitude of impacts on total value. However, this aggregated national data masks important local level differences in impacts on yields. For example, the results for yield change of maize from 2000 to 2050 at district level are in a range of -74 percent to +44 percent (IFPRI dataset for CSIRO climate model). Therefore, the national level results need to be informed also with bottom-up assessments, including from the forthcoming case studies for this project. See also the next section for a regional analysis.
- A key crop for livelihoods and food security in Uganda that is not included in the IFPRI modelling is the banana (matooke). The UNDP (2013) study reports that in Uganda increased temperatures are expected to favour matooke production although there is potentially significant increased risk from pests and diseases on the crop is significant.

Regional Level Analysis of Selected Crops

To further inform the national level assessment a regional level analysis of climate change impacts on production and value has been undertaken for four key crops in Uganda. These results have been calculated based on district level yield change estimates for maize, sorghum, soybean, and rice to 2050 provided by IFPRI (district level data for other crops were not available). These estimates are from four climate models (CNRM, CSIRO, ECHAM and MIROC) for the A1B emissions scenario only (see Annex 1 for further explanation of the methodology).

The estimated district yield change percentages have been aggregated at the level of the four regions of Uganda (Central (C), North (N), East (E) and West (W)). Table 3.1 shows these average yield change percentages per region for the four climate models. The table illustrates the differences in estimates produced by the four models and the differences in estimated yield changes between regions with, in general, the Eastern and Northern regions estimated to experience the larger impacts.

Table 3.1: Estimated average yield change (%) due to climate change (2000 to 2050) per Region.

Region/Model	CNRM	CSIRO	ECHAM	MIROC
Maize				
Central	-7.9	-0.2	-2.6	2.2
Eastern	-12.0	6.5	5.0	7.4
Northern	-12.2	-14.4	-8.7	11.9
Western	-2.6	-3.5	-6.6	7.6
Sorghum				
Central	-1.5	3.5	4.3	10.3
Eastern	-15.9	-2.9	-13.3	-4.5
Northern	-17.5	-11.4	-14.2	1.6
Western	8.4	-3.4	2.8	13.5
Rice RF				
Central	6.1	9.5	12.5	15.9
Eastern	-7.9	0.5	0.1	-0.7
Northern	-20.7	-7.0	-6.3	12.0
Western	23.9	13.0	1.7	23.8
Soybean				
Central	-24.6	-12.3	-19.2	-14.9
Eastern	-20.7	-4.4	-18.1	-9.0
Northern	-24.1	-8.4	-16.4	-9.2
Western	-16.7	-9.2	-17.9	-7.8

Source: Calculated from IFPRI data

Based on these yield change estimates we have made estimates for regional production changes to 2050 due to climate change. Figure 3.6 gives the estimated percentage of production difference due to climate change compared with the no climate change scenario in 2050 per region. This assumes an annual percentage crop production increase of 1.9 per cent per annum based on projections for Sub Saharan Africa in Alexandratos & Bruinsma (2012). Based on the above production estimates, estimates for value changes to 2050 due to climate change were made based on market prices in Uganda. Figure 3.7 shows the estimated percentage of value difference due to climate change compared with the no climate change scenario in 2050 per region.

Figure 3.6: Estimated production difference due to climate change compared with no climate change scenario in 2050 per region (%).

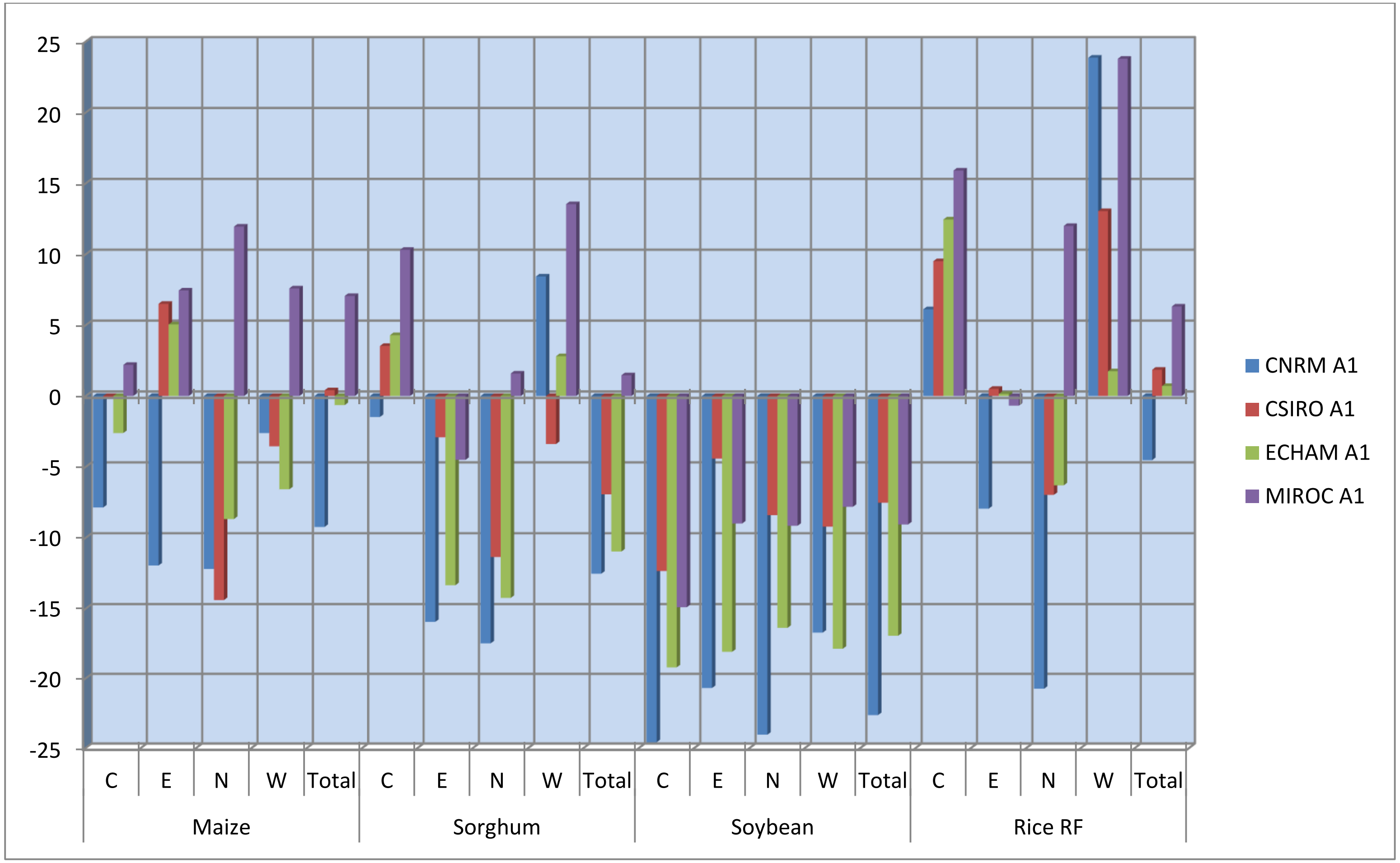
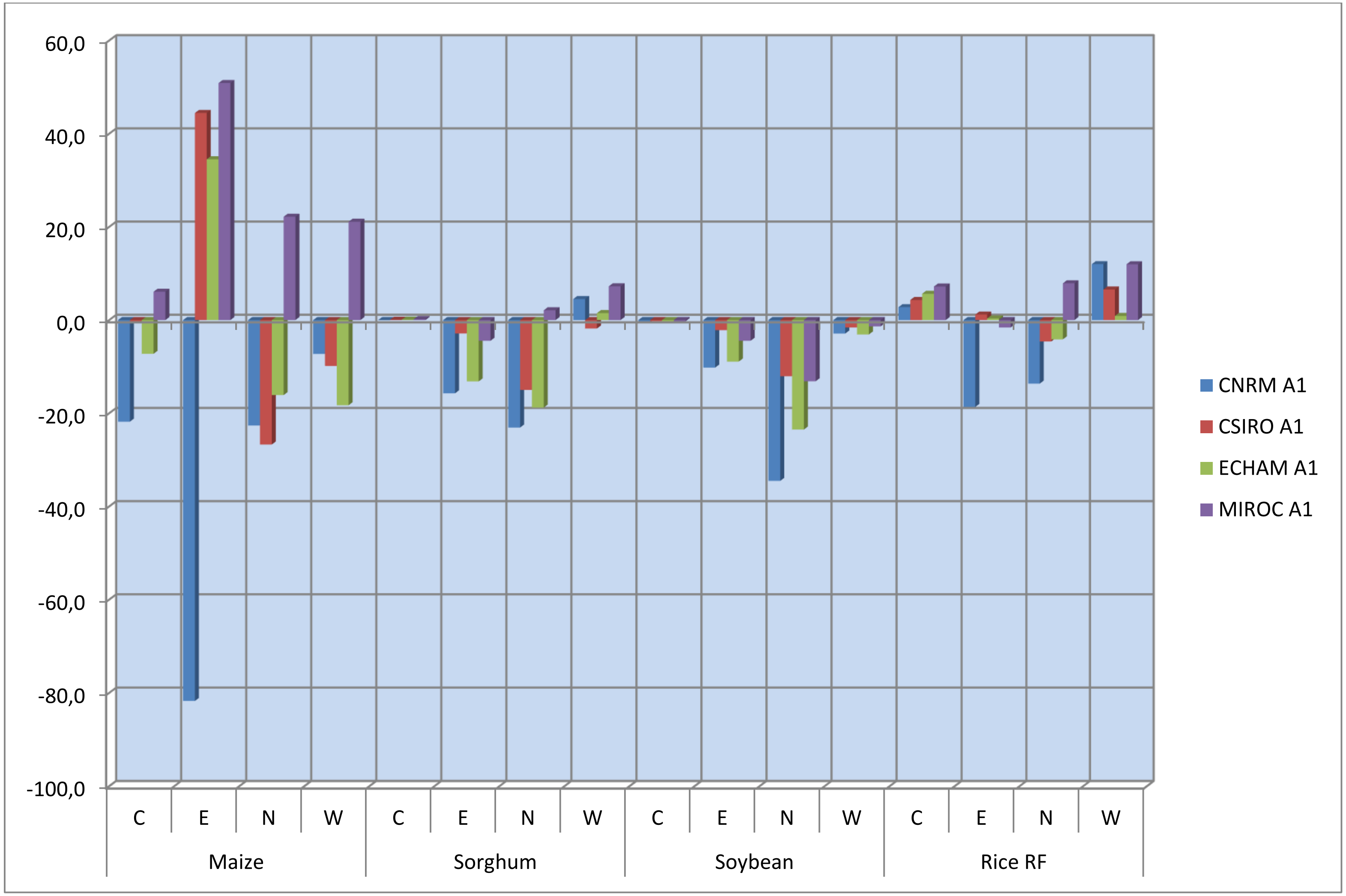


Figure 3.7: Estimated value difference due to climate change compared with no climate change scenario in 2050 per region (%).



Preliminary findings for the regional level assessment of food crops are as follows:

- **The regional assessment was necessarily limited in selection of crops to assess** due to limited availability of district level crop yield estimates from IFPRI. Nevertheless it seeks to illustrate regional variations in impacts of climate change on production and value. These IFPRI estimates of district level crop yield impacts have significant variation within regions. This underlines the importance of further case study assessment to highlight where there may be heightened local impacts on agriculture that are above the national and regional averages.
- **Difference between models**: Results for production and value changes show great divergence between different climate models. CNRM shows the most consistent losses in production and value for all crops analysed. MIROC gives the least impacts and in some cases, such as maize, shows increases in production. This is consistent with the very modest temperature increases and significant rainfall increases of this model. Both the CSIRO Mark 3 and the ECHAM 5 models predict mostly yield reductions from climate change (with some exceptions such as for Maize in Eastern region) but less than CNRM.
- **Differences between regions (Production and Value):** Largest impacts are shown in the East and North for all crops. For maize, soybean and sorghum the models show most of the economic impacts (positive and negative) in the East and North. For example, for maize about 80 percent of the estimated loss of value in 2050 is in these regions under the CNRM model. Results for maize from Waithaka, M. et al (2012, Figure 12.15) also show key impacts in these regions.

4. SUMMARY OF ASSESSMENT OF IMPACTS OF CLIMATE CHANGE ON AGRICULTURAL EXPORTS

The agriculture sector of Uganda contributes a significant share of total exports, with the "food, animals and beverages, tobacco" category being the largest commodity group for exports in 2013 representing 49.9 per cent of total export value or about US$1200 million. This category of exports has seen an average annual growth rate from 2009 to 2013 of about 13 per cent . Key export crops are coffee (from 2011 to 2013, the largest export commodity contributing about 18 percent to total export value), tea (3.1 percent in 2012), cotton (3.2 percent in 2012) and tobacco (3 percent in 2012). Other significant crop exports are maize (2.4 percent), rice (1.6 percent), cocoa beans (1. 6 percent), cut flowers (1.1 percent), beans (0.6 percent) and sesame seeds (0.5 percent) (UBOS, 2013). In this section we focus on the potential impacts of climate change on production and exports of coffee, tea and cotton.

4.1.1. Coffee Exports

Coffee is a key cash crop of Uganda. Total production was 186,126 tonnes in 2012 (FAOstat 2014) of which Arabica was 53,404 tonnes and Robusta 133,458 tonnes. Robusta is grown extensively in a 300 km radius around Lake Victoria and in some other regions. Arabica is grown around Mount Elgon in the east, the mountain ranges in West Nile and Mount Ruwenzori in South West Uganda. Over 500,000 households are involved in cultivating Arabica and nearly 1 million in cultivating Robusta.

Total coffee exports were about 215,000 tonnes in 2012/13 with a total value of US$433m (UCDA). This represented about 18 per cent of total exports from Uganda, although there has been great volatility in the total volume and value of coffee exports over recent decades.

4.1.2. Climate Risks for Coffee Production

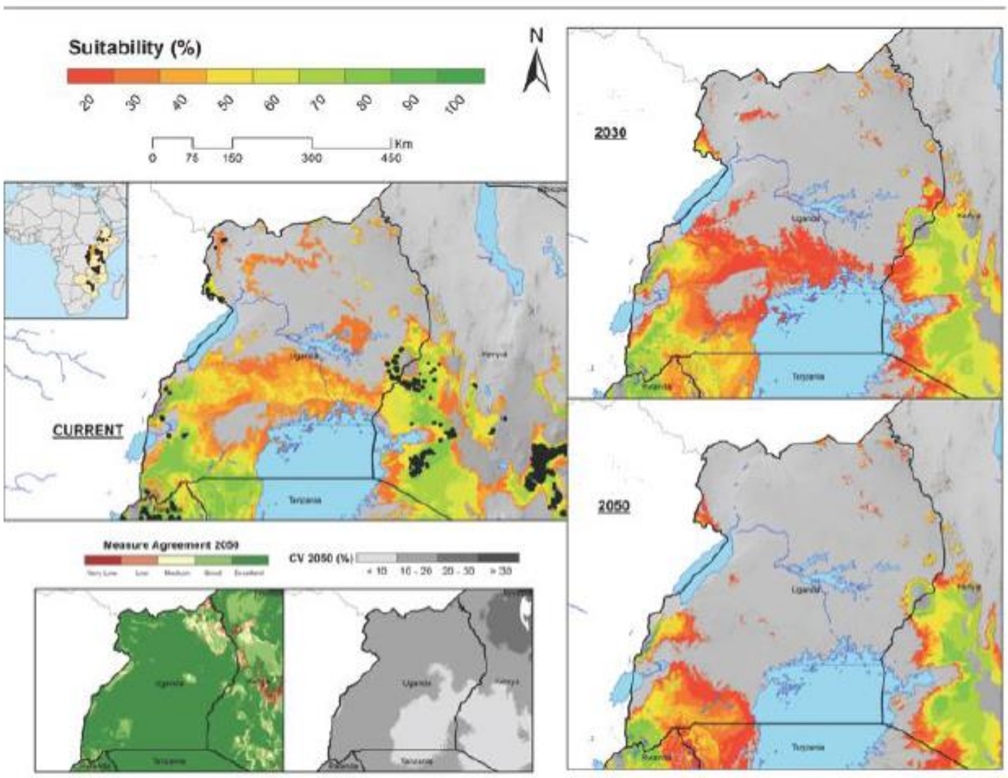
Coffee production globally is especially sensitive to climate variability and change. Both Robusta and Arabica coffee have high but different sensitivities to changing temperature and rainfall conditions. Optimal growing conditions for Robusta require slightly higher temperatures and rainfall than Arabica and it is much less adaptable to lower temperatures than Arabica (Haggar & Schepp, 2012). Furthermore, floods and droughts can have direct impacts on coffee tree growth owing to their shallow roots. During the 1997/1998 floods, coffee exports dropped by 60 percent (UNDP 2013). In addition, increases in temperature are forecast to foment the development of pests such as the coffee berry borer in parts of East Africa (UNDP, 2013). A further factor that is not well understood is the response of coffee to increased carbon dioxide concentrations from climate change (indeed this is true for many crops). This fertilisation effect may partially offset some of the negative consequences of changing temperature and rainfall.

High fluctuations in coffee production in Uganda in the last 40 years have been mainly attributed to climate variability. There has also been some downward secular trend due to factors such as reduced soil fertility and mismanagement (UNDP, 2013). However, there is limited data to confirm a correlation between coffee production and climate change. It is important to note here that different varieties of Robusta and Arabica with varying sensitivity to climate hazards are grown in different districts in Uganda. Thus for a fuller understanding of climate impacts in Uganda further research is needed through crop modelling based on specific varieties grown in different districts.

Most of the studies of projected impact of climate change on coffee in the literature (Annex 2) show consistently significant global declines in areas suitable for cultivation under different emissions scenarios. Most work has focused on Arabica with recent studies by CGIAR including assessment of future suitability of growing areas in Uganda under the SRES-A2a scenario (CIAT, 2013; Läderach & van Asten 2012; and Jassogne, Läderach & Van Asten, 2013). Figure 4.1 gives the findings on suitability for production of Arabica across regions in Uganda for the current period and predictions for 2030, and 2050. This show a great reduction of areas suitable for production by 2030 and a huge increase in area that is not at all suitable for coffee growing by 2050.

Much less work has been done on the impacts of climate change on Robusta even though this accounts for higher percentage of production than Arabica in Uganda. The most commonly cited forecast for Robusta is by Simonett (1989) which gives maps showing a drastic decline in suitable growing area in Uganda caused by a 2% rise in temperature. However, the map was produced in 1989 and Haggar & Schepp (2012) conclude that "it is not clear what the scientific basis is of the prediction for Uganda, so any extrapolation must also be considered speculative."

Figure 4.1: Predicted suitability for coffee production in Arabica coffee-producing area in Uganda (Current, 2030, and 2050).



The coefficient of variation (CV) and measure of agreement (ME) is shown for the study area with the points (black dots) representing the sampled *Coffea Arabica* farms (large map); adapted from Läderach and van Asten (2012).

4.1.3. Economic Impacts on Coffee from Climate Risks

Impacts of climate change on the global coffee industry are potentially very significant. A number of reports highlight the potential for significant future value losses of coffee production in Uganda. For example, climate-induced yield losses in the order of 10–50 percent, potentially reducing foreign exchange revenue by US$15–80m per year, are cited in the recent Oxfam Research Report (Jassogne et al, 2013). Another source suggests that a shift in the viability of coffee growing areas could potentially reduce export revenue by 40 percent (MAAIF, 2010).

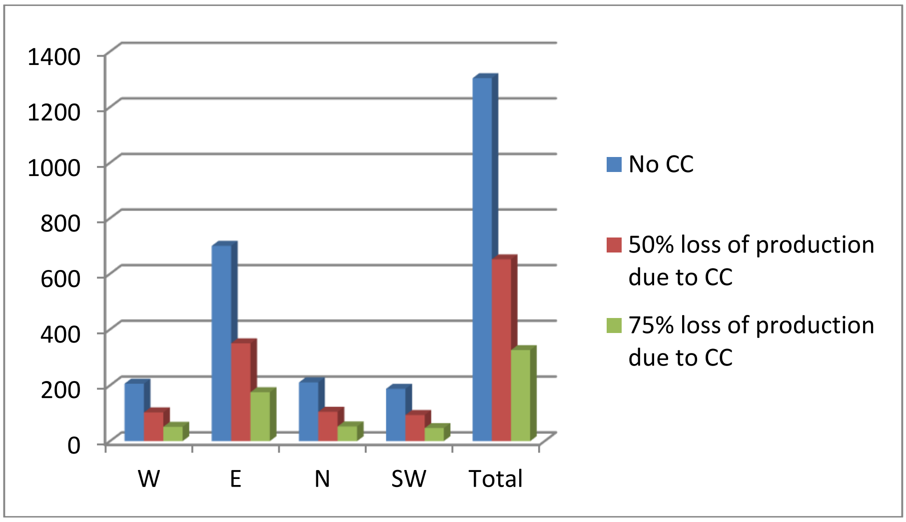
For this study an assessment of potential future loss of coffee production and export value has been made for Uganda by region based on UCDA data on cultivated areas for Arabica and Robusta coffee. A detailed explanation of methodology and results is given in Annex 2. It is stressed that these projections are not forecasts but illustrative of economic impacts under plausible different scenarios of future yield, production and price.

4.1.4. Impacts on Production of Coffee

Current studies of changes in suitability for Arabica coffee production do not provide an appropriate dataset to make credible estimates of how these changes in areas will translate to changes in production. Therefore, to provide an illustration on potential economic impacts future coffee production in 2050 has been estimated under assumptions of 50 percent and 75 percent reductions in production which we believe are realistic for the projected significant losses of suitable growing areas estimated in recent studies, in particular those by CGIAR cited above. These estimates assume yield improvements of 1.9% per year to 2050, due to improved techniques, for those areas that remain in cultivation[7].

Figure 4.2 shows results under these assumptions for total and regional production in 2050. The scale of potential differences in production between scenarios without climate change and with climate change scenarios is significant. A 50 percent reduction in national production due to climate change would amount to about 39,000 tonnes in 2050 (650,000 x 60 kg bags) and a 75 percent reduction in production to about 59,000 tonnes (978,000 x 60 kg bags).

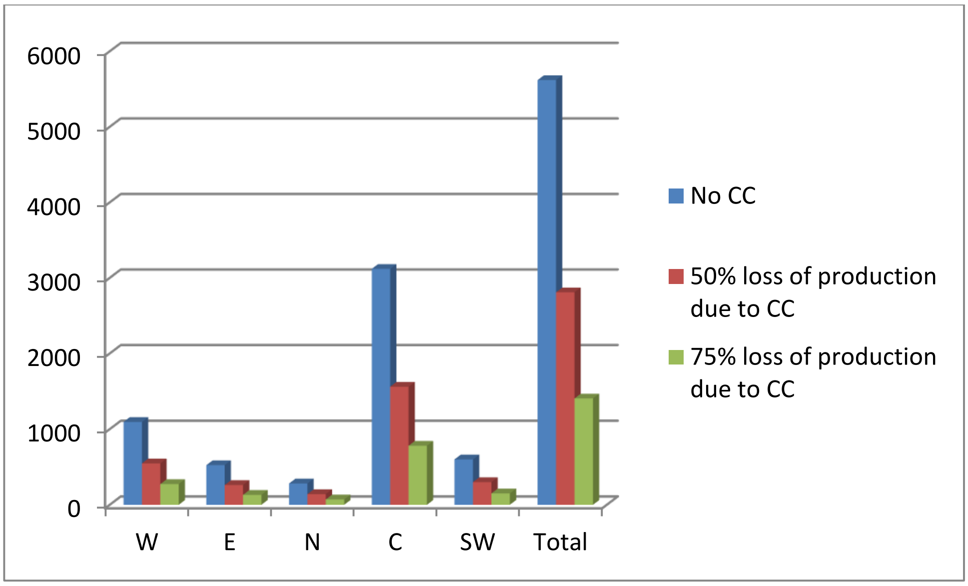
Figure 4.2: Arabica Coffee: Estimated Impacts of Climate Change on Production in 2050 (1000 x 60kg bags)



Estimates were also made for Robusta coffee production in 2050 using the same assumptions as above for Arabica (Figure 4.3). Since research on climate change impacts on Robusta coffee growing areas is much less developed than for Arabica these results should be treated with greater caution as they are simply illustrative of production impacts under the assumed scenarios.

[7] Based on crop projections for Sub Saharan Africa in Alexandratos & Bruinsma (2012).

Figure 4.3: Robusta Coffee: Estimated Impacts of Climate Change on Production in 2050 (1000 x 60kg bags)



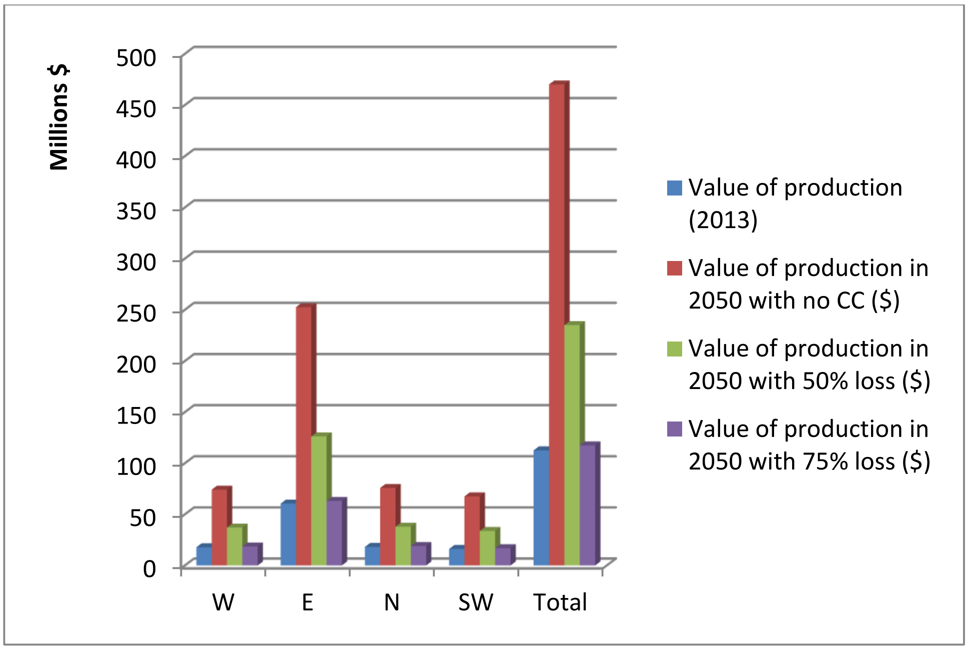
Impacts on Value of Coffee

The value of production in 2013 for each district and region of Uganda was estimated based on price data for Arabica and Robusta.

Estimates of the impacts of climate change on the value of coffee production in Uganda in 2050 were made under the assumptions of 50 percent and 75 percent reductions in production. These estimates assume yield improvements as in the production estimates above, and coffee price increases of 2% p.a[8]. Figure 4.4 shows results for total and regional value of production in 2050 for Arabica coffee, under the above assumptions with a comparison to values for 2013. In this scenario the total difference in value between no reduction in production and 50 percent reduction in production due to climate change is estimated at US$235 million in 2050; and this figure rises to about US$350 million in the 75 percent reduction in production scenario. Over half of this reduction in revenue would be experienced in the key Arabica growing areas in the Eastern region.

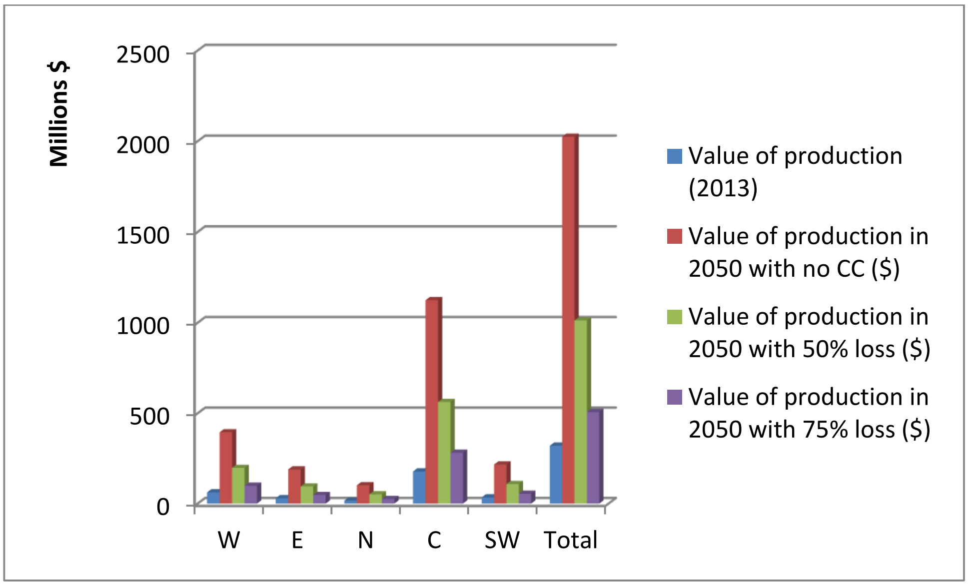
[8] These estimates have been made assuming the same yield improvements for those areas that remain in cultivation as those used for production estimates in Figures 4.2 and 4.3.

Figure 4.4: Arabica Coffee: Value of Production in 2050 with yield improvements and price increase of 2% p.a (million US$).



Estimates were also made for the value of Robusta coffee production in 2050 using the same assumptions as above for Arabica (Figure 4.5). As pointed out above these results are only illustrative of value impacts under assumed scenarios for loss of cultivation areas as there are no up to date projections on climate change impacts on Robusta coffee growing areas. In this scenario the total difference in value between no reduction in production and 50 percent reduction in production due to climate change is estimated at US$1,000 million in 2050; and this figure rises to about US$1500 million in the 75 percent reduction in production scenario.

Figure 4.5: Robusta Coffee: Value of Production in 2050 with yield improvements and price increase of 2% p.a (million US$).



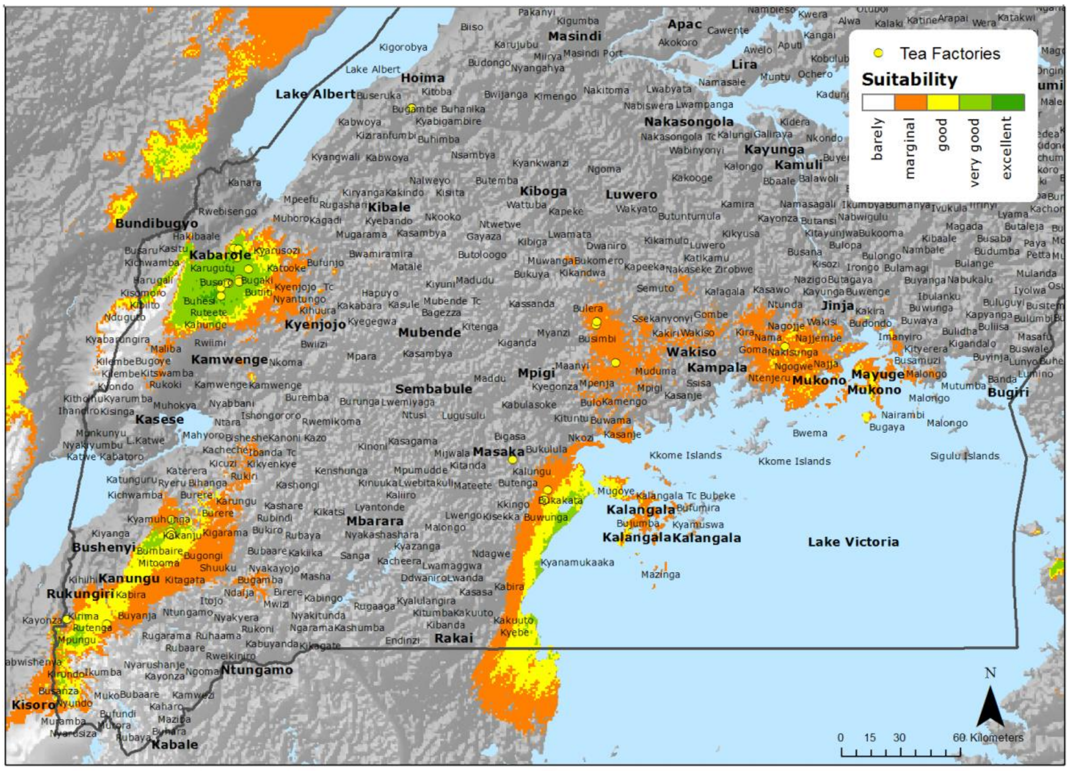
4.1.5. Tea Exports

Tea production in Uganda is an important export crop currently employing about 60,000 small scale farmers. In 2012 the total cultivation area was about 27,000 ha (FAOstat database) and export production was about 55,210 tonnes[9] which rose to 62,000 tonnes in 2013 with a trade value of about US$85m[10], over 3 percent of total export revenues for Uganda.

The key study by CIAT (2011), "Future Climate Scenarios for Uganda's Tea Growing Areas", concludes that as a result of projected changes in rainfall and temperature the area of suitability in the current tea growing areas in Uganda will decrease quite substantially by 2050. Figures 4.6, 4.7 and 4.8 indicate reducing areas of suitability for tea production from current to 2020 and 2050.

As in the case of coffee, the geographical representation of predicted changes in suitability for tea (only for SRES-A2 scenario) does not provide us with an appropriate dataset to make credible estimates of how these changes in areas of suitability will translate to changes in production potential at the administrative district, regional and national level. However, it is clear that the significant losses in growing area, without compensating increases in growing area available elsewhere in Uganda, will have significant impacts on the current value of tea exports These exports had a value of about US$74 million in 2012, which rose to US$85 million in 2013[11]. To give an illustration of the potential scale of those impacts, a 50 per cent fall in tea production would result in a loss of about US$175 million in exports in 2050 under the same assumptions as those used for the illustration of impacts on coffee above (i.e. a 1.9 percent annual increase in production for those areas still in production and a 2 percent per year price increase).

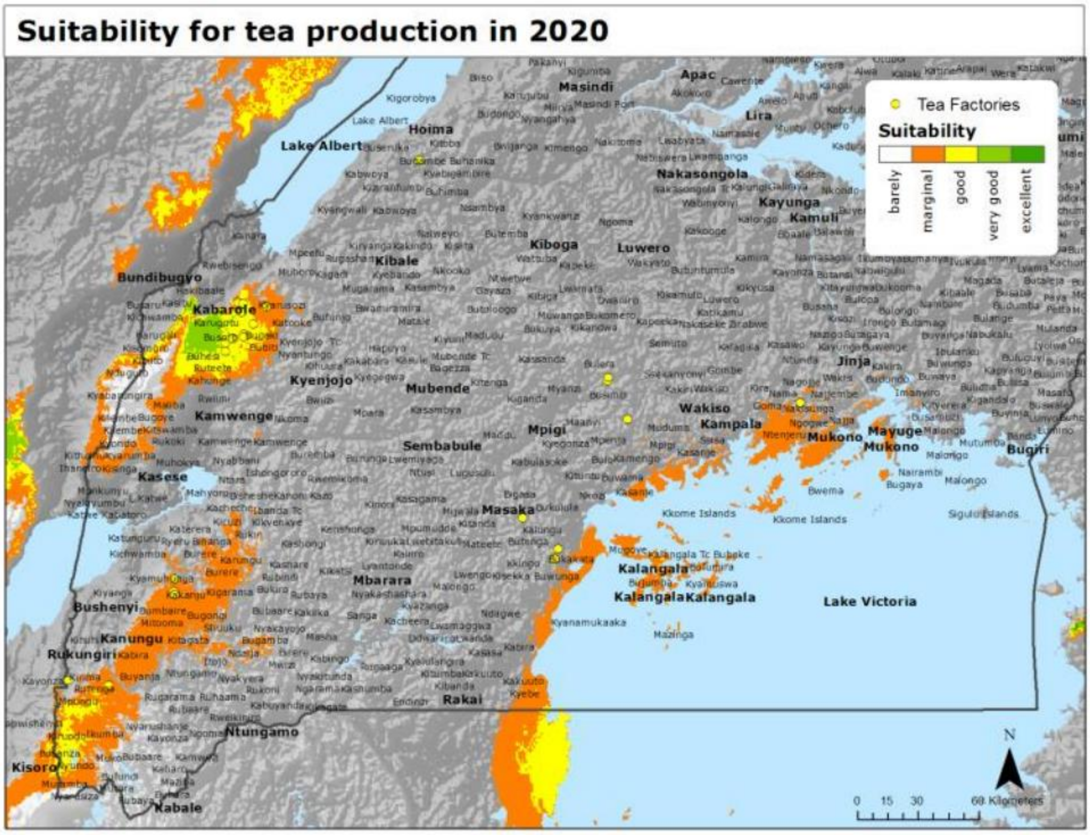
Figure 4.6: Current suitability of tea production areas



Source: CIAT (2011)

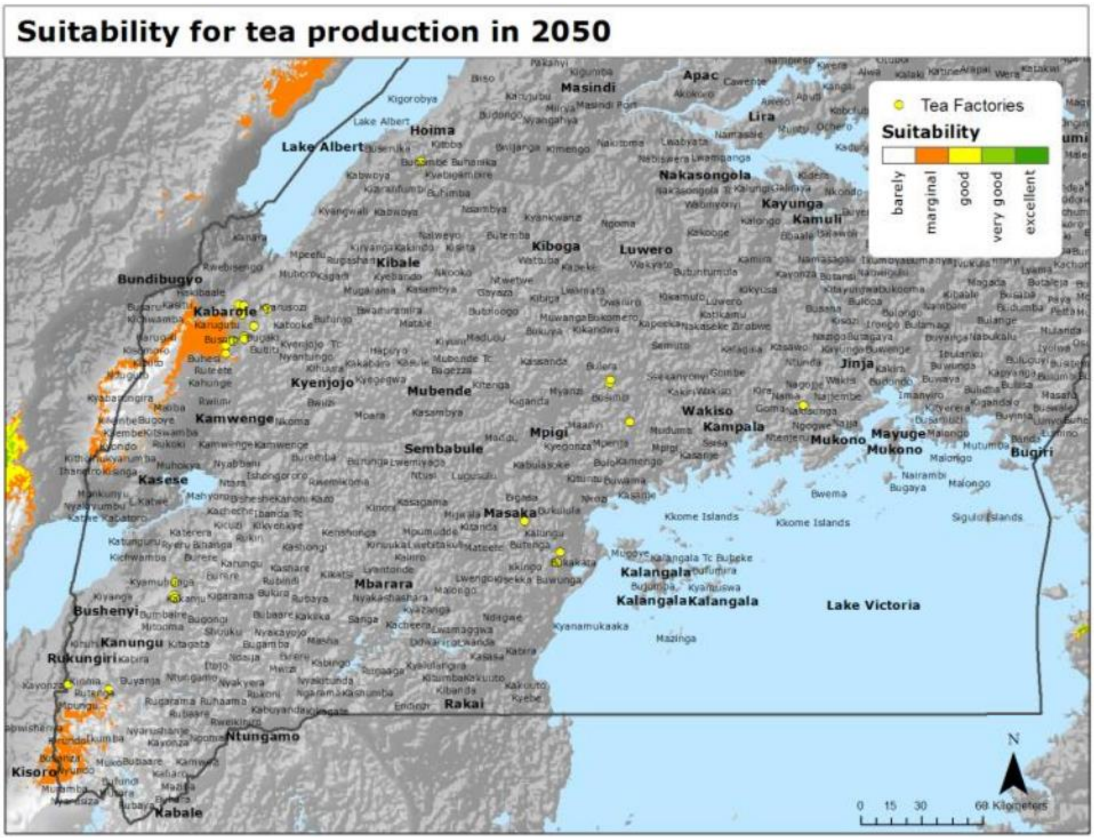
[9] Source is UN Comtrade database. Exports given as 54,855 tonnes (2012) in Statistical Abstracts 2013. Uganda Bureau of Statistics (UBOS), Statistics House Kampala.
[10] UN Comtrade database: http://comtrade.un.org/data/
[11] UN Comtrade database: http://comtrade.un.org/data/

Figure 4.7: Future suitability of tea production areas (2020)



Source: CIAT (2011)

Figure 4.8: Future suitability of tea production areas (2050)



Source: CIAT (2011)

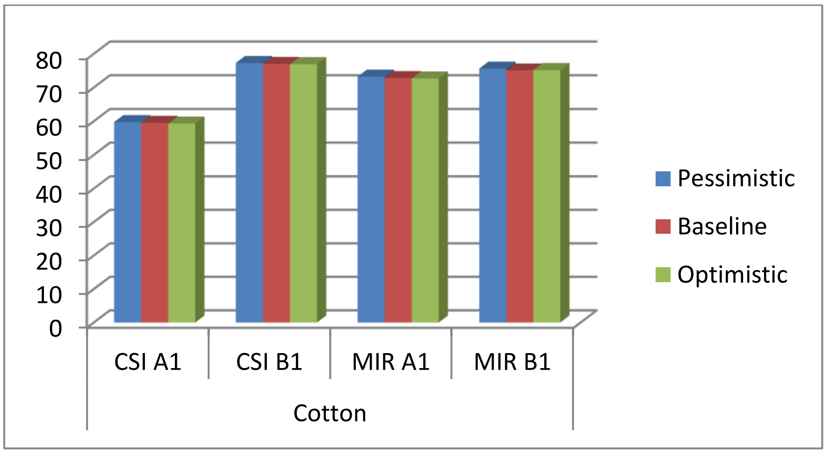
4.1.6. Cotton Exports

Cotton is among the top agricultural exports of Uganda with a trade value in 2012 of US$76,934,316 and in 2013 of US$32,868,863[12]. This fall is attributed to a drop in production due to dry spells, low soil fertility and limited use of fertilizers[13]. An estimated 250,000 households produce or earn their livelihood from this crop. Moreover, there is potential to increase production with two thirds of arable land suitable for cotton cultivation according to industry sources (ITC, 2011a).

Existing global studies (see for example, ITC, 2011b) highlight potential impacts on cotton yields through increased atmospheric CO_2, changes in temperature, rainfall, soil moisture, and evapo-transpiration rates, and increased levels of pests and diseases.

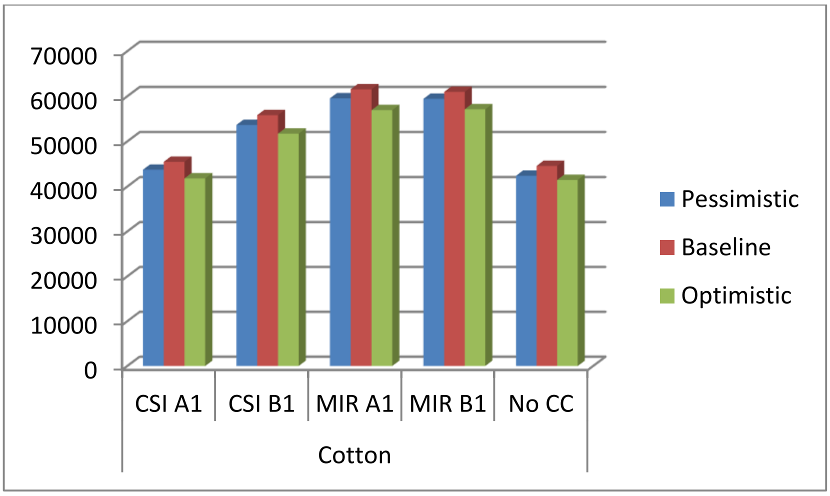
The literature search did not find any dedicated studies on climate change impacts on cotton in Uganda. However, the IFPRI modelling data includes cotton among the crops analysed for impacts of climate change. Results of estimates of impacts on cotton production and value in Uganda in 2050 using the IFPRI data are given in Figures 4.9 and 4.10 under the different climate and socio economic scenarios (see Section 3 and Annex 1 for an explanation of this methodology, and the climate models and socio economic scenarios used). Figure 4.9 shows that under the four climate change scenarios modelled production in 2050 would be reduced to between 60 and 77 percent of the no climate change scenario. Figure 4.10 indicates that under the climate change scenarios the total value of may be higher than under the no climate change scenario. This is due to the considerably higher international price projections used by IFPRI for climate change scenarios compared to the no climate change scenario. As in the case of the modelling of food crops, the projections for future value of cotton should be treated with great caution due to the great uncertainties that come with price projections to 2050.

Figure 4.9: Cotton production in climate change scenarios as a percentage of production without climate change in 2050 (%)



[12] UN Comtrade database: http://comtrade.un.org/data/
[13] " Uganda Faces Decline in Coffee and Cotton Earnings, *East African Business Week*, October 2014 https://busiweek.com/index1.php?Ctp=2&pl=1997&pLv=3&srl=89&spl=525&cl=25

Figure 4.10: Cotton value in climate change scenarios in 2050 (USD 1000 at 2000 prices)

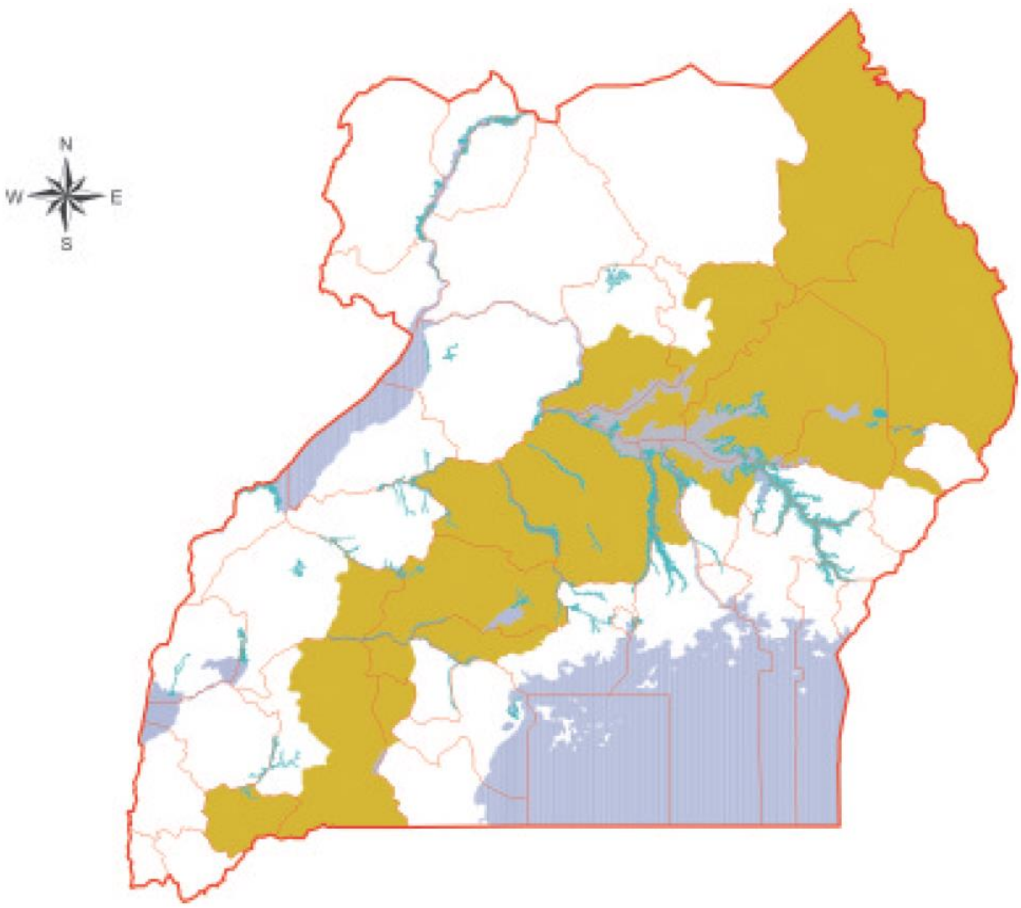


5. IMPACTS OF EXTREME CLIMATE HAZARDS: DROUGHTS AND FLOODS

The previous sections have focused on the impacts on agricultural yields and production of climate change scenarios in terms of overall annual and seasonal rainfall and temperature. This does not take into account the specific impacts of extreme weather conditions that may have sudden and significant impacts on production and livelihoods, and which may become more frequent and more intense under future climate change scenarios.

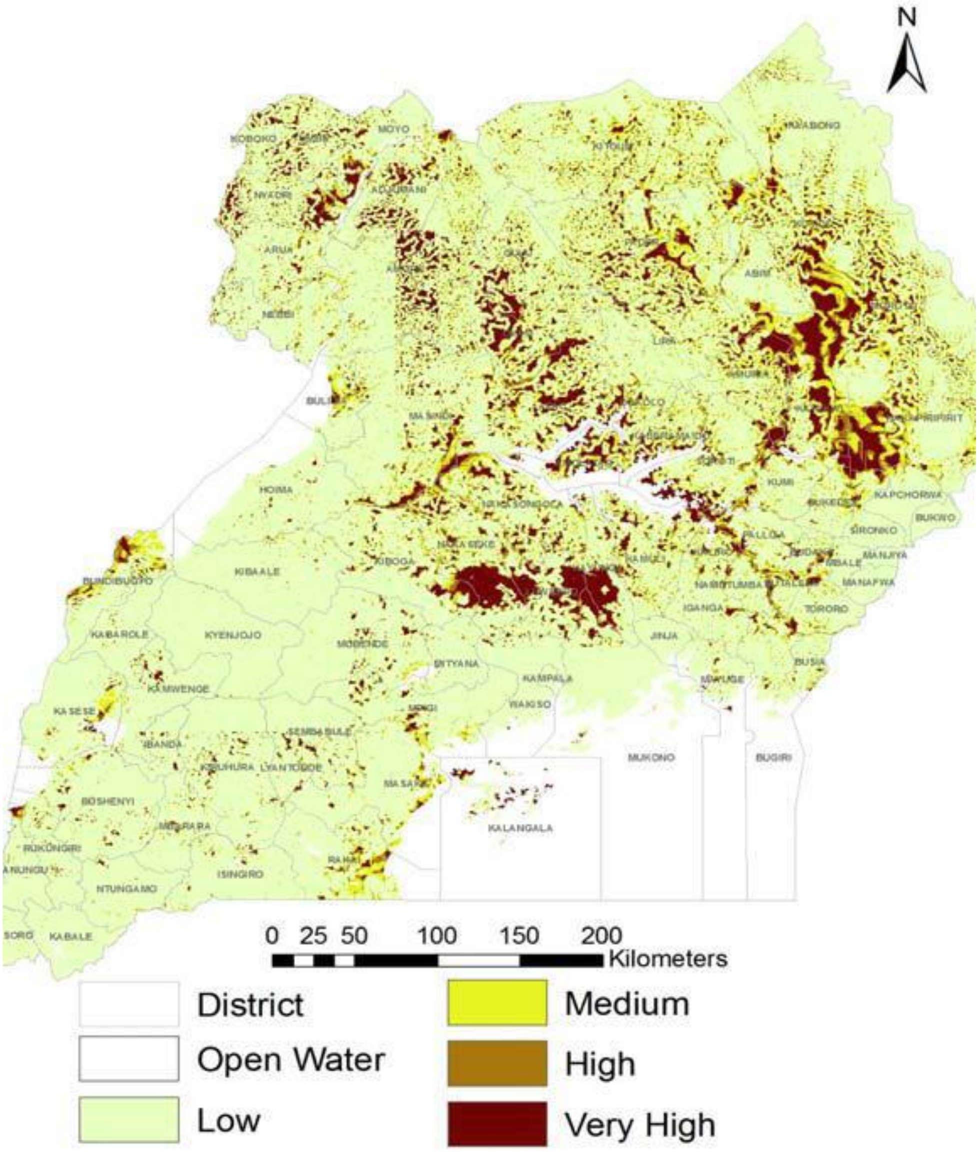
Uganda is already vulnerable to extreme weather events in the form of floods and droughts. In their study of African county data since 1960, Shi & Tao (2014) note that the country is in the group of countries with the highest drought impacts. The northern region is particularly prone to floods and droughts as a result of high rainfall variability, with food security especially affected, for example, in the Karamoja region. On average, 30 percent of food needs are covered by aid in this region (USAID, 2011). Droughts are also frequent in the cattle corridor (an area stretching from northeast, through central to southwest Uganda covering approximately 84,000 sq. km. or about 40 percent of the total area of Uganda) due to regular low levels of rainfall combined with poor soil fertility (UNDP, 2013). Figure 5.1 shows drought affected areas of the cattle corridor and Figure 5.2 shows flood prone areas of the country.

Figure 5.1: Drought Affected Areas of the Cattle Corridor



Source: NAPA, 2007

Figure 5.2 Flood-prone areas in Uganda



Source: NEMA (2008)

The Ugandan Agricultural Census (UBOS 2010) reported that about 7 percent of the total of 3.95 million agricultural households was prone to flooding, mostly in the Eastern Region. Between 1900 and 2011 the country experienced 16 major flooding events, affecting about 1 million people in total, and 9 major droughts, affecting about 5 million people. It is striking that 8 out of the 10 most severe floods and droughts in terms of numbers affected since 1900 have occurred within the last 20 years (CRED, 2014). This supports claims that extreme weather events have been increasing in recent years. In particular, the evidence suggests that droughts are becoming more frequent and more severe with major events occurring in 2001, 2002, 2005 and 2008 (UNDP, 2013). In Karamoja severe droughts are now occurring every two to three years as opposed to approximately every five years in the past. This is devastating for the food security of local populations since it takes an estimated two years to recover from each such drought (USAID, 2011).

Table 5.1 gives estimates of economic damages for the most severe floods and droughts in recent years from the CRED Database. These estimates are for direct consequences on the local economy (e.g. damage to infrastructure, crops, housing) and not indirect consequences (e.g. loss of revenues and unemployment). Caution is advised by CRED authors on account of the low reporting rates of direct losses (although this is generally improved for large disasters, Guha-Sapir et al, 2013). Unfortunately, these damage estimates for Uganda do not separate damages by sector and therefore we do not know the extent to which the direct damages were agriculture-related. Given the location of most flooding we can surmise, however, that a significant part of these damages were to the agricultural sector.

Table 5.1: Economic damage costs of most severe floods and droughts in Uganda

Event	Date	Damage (million US$)
Flood	May 2013	3.1
Drought	Jan 1998	1.6
Flood	Nov 1997	1.0
Drought	Jan 1967	0.2
Flood	Aug 2007	0.07

Source: CRED (2014) International Disasters Database

The report on the impact of the 2010 – 2011 rainfall deficits by the Department of Disaster Management/Office of the Prime Minister (OPM, 2012) gives detailed estimates for damage and production losses. It uses the DaLA (Damage, Loss and Needs Assessment) methodology to estimate the effects of drought by sector and gives an overall estimate for 2010 when there was a severe drought in the country. The estimate of loss and damage was 2.8 trillion shillings (US$ 1.2 billion) or about 7.5 percent of Uganda's GDP in that year.

These damage and losses were heavily concentrated on the agricultural sector with livestock accounting for 1.1 trillion Shillings or about US$ 470 million, 40.3 percent of the total, and the production of food and cash crops accounting for 1.0 trillion Shillings (of which about 0.9 trillion Shillings was for food crops), 37.0 percent of the total. Much of the impacts to cash crops were losses to Robusta coffee production of approximately 97.75 billion Shillings. The agricultural sector also required a high proportion of total recovery and reconstruction needs, with about 32 percent for activities related to food and cash crops and about 43 percent related to livestock. In addition the agro-industry, including processing of coffee, tea, sugar, tobacco and grains, had high losses of about 278.0 billion Shillings, 10 percent of the total.

The OPM (2012) report also provides estimates for losses caused by the 2005-2007 drought. Losses totalled 126 billion shillings for the agricultural sector with livestock accounting for about 12 billion Shillings and the production of food and cash crops accounting for about 114 billion Shillings, of which about 112 billion Shillings was for cash crops. The agro-industry had losses of about 98 million Shillings. These losses were about 0.7 percent of GDP in 2006.

Other event specific estimates of damages to agriculture cited in the literature include for:

- 1997/1998 floods which resulted in coffee exports falling 60 percent and tea estate operations being suspended in the eastern region (MWE 2002, quoted in UNDP 2013),
- September 2010 floods in the Teso[14] area which caused damage to cassava, sweet potato tubers and groundnuts valued at over US$3.1 million.

[14] From 2007 to date the Teso sub region has experienced major floods in November that have been intermittently followed by long droughts and floods during traditional planting seasons. This has significantly impacted the planting strategies in the sub region.

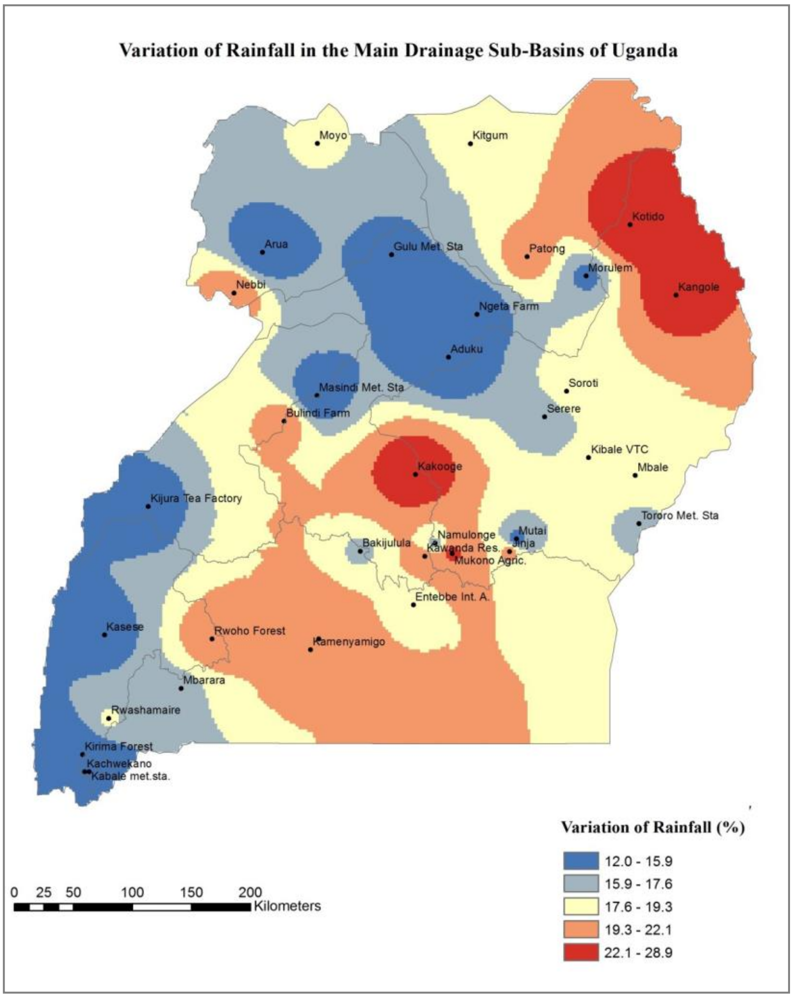
- 1999/2000 droughts which caused the water table to lower with drying of wells and boreholes resulting in cattle deaths, low milk production and food insecurity within the cattle corridor (NEMA, 2008).
- Flooding in July-September 2007 in the Amuria and Katakwi Districts of Teso causing high crop losses. Estimates of losses of cultivated area and production per crop are given in the FAO (2008) assessment report. The cost of flood damage in Teso sub-region covering six districts of Amuria, Katakwi, Bukedea, Kaberamaido, Kumi and Soroti was estimated at UgShs120 billion, although this seems to be based on reconstruction costs rather than agricultural losses (Kajubi, 2012).

National estimates of extreme weather event related damages to agriculture include:

- Average losses of 800,000 ha of crops per year, causing losses of over US$47million (NEMA, 2008).
- Losses due to "bad weather can sometimes reach 30 percent of the annual agricultural production" (UNEP/UNDP, 2009).
- Brown et al. (2011) find a significant and negative correlation between drought and GDP growth per capita: a 1 percent increase in the area of a Sub-Saharan African country experiencing moderate drought correlates with a 2–4 percent decrease in GDP growth (World Bank 2013).

A key question is the extent to which recent trends in flooding and drought will continue into the future. The study by Rautenbach (2014) provides spatial detail on areas facing higher risks of these events. It calculated the percentage of the coefficient of variation in inter-annual rainfall on a spatial scale for Uganda and found a range from 13 to 29 percent. Areas where value is greater than 20 percent are more likely to experience more frequent and severe droughts or floods. Such high variations in inter-annual rainfall were found at the Kakooge, Kotido and Kangole stations (south and north-east of Uganda), while the Aduku, Kirima Forest, Masindi Meteorological and Ngetta Farm stations had the lowest variations (south-west and north-west of Uganda) (see Figure 5.3 reproduced from the Rautenbach 2014 study). It was also concluded that rainfall, for example at the Kakooge station, has varied more over the past 30 years than the 30 years before that, implying that this station is at risk of experiencing more droughts in the future .

Figure 5.3: Percentage of the coefficient of variation in inter-annual rainfall as calculated at 36 rainfall stations across Uganda over the period 1940 to 2009.



According to studies, areas in orange and red are facing a higher risk for droughts than areas in blue

The available damages estimates discussed above do not allow a detailed national economic assessment of the future impacts on agriculture from extreme weather events. This is because the local estimates of economic damages occurring in recent years are very site specific and do not provide a basis for aggregate national estimates. In addition, the few national estimates of damages vary widely in order of magnitude and their methodology and the scope of agricultural production covered is unclear. Moreover, while it is widely accepted that extreme weather events have been increasing and becoming more severe in recent years and the analysis by Rautenbach concludes that these risks are likely to increase in the future in large parts of Uganda, there are no quantitative projections for these risk factors under different climate change scenarios on which to base projections of future economic damages.

To give an indication of the order of magnitude of losses, the OPM (2012) estimate of losses of about US$470 million to food crops, cash crops and livestock as a whole resulting from the 2010-11 drought equates to about 16 percent of the total value of these items in GDP for 2011. The damage figure of US$47million per year to crops (given in NEMA, 2008) is equal to about 3 per cent[1] of the value of all cash and food crops in 2008. If we take the estimate that losses can reach 30 percent of the annual agricultural production (in UNEP/UNDP2009) this would be equal to about US$1,300 million based on total GDP for the sector in 2012,

[1] Calculations based on GDP data for the agricultural sector in UBOS (2013).

including livestock. This calculation assumes the 30 percent production loss equates to a reduction of 30 percent in sector value. Clearly, if future climate change is to increase the risk of experiencing more droughts and floods the total economic damages would increase above the current range of estimates in the absence of adaptation actions to limit the impacts. It should also be stressed that predicted future increased risks are in areas of existing food insecurity and therefore the economic and social consequences are more complex than simply the loss of production value that we have focused on in this section.

6. CONCLUSIONS AND PRIORITIES FOR ADAPTATION

6.1.1. Findings from the Economic Assessment:

6.1.1.1. Costs of Inaction

In the absence of additional measures to adapt to climate change there will be consequences in three areas: on food crops and livestock, on export crops, and on both of these sectors from extreme events.

Food crops: Climate impacts on regular farming are hard to predict. The very sophisticated models used for this purpose show wide divergence on what will happen to the output of 11 staples that have been modelled (cassava, groundnuts, maize, millet, pigeon peas, potatoes, rice, sorghum, soybean, sugar cane and sweet potato). Most of them indicate some decline up to 2050 but some even point to a possible increase. The largest falls are predicted for cassava, potato and sweet potato, which could decline by as much as 40% by 2050. In most cases, however, the decline in yields is less than 10%. Under the scenarios considered overall losses for food crops by 2050 are not likely to be more than US$1.5 billion and could well be less than that. Under the assumed growth in the economy this would be less than 0.2 percent of GDP in that year. It is important to note, however, that these national figures, mask important local differences in yields and value of production. In the regional analysis the largest impacts on production and total value are shown in the East and North for all crops

Livestock products impacts on production are quite small in all cases (1 or 2%) based on the IFPRI modelling. However, this modelling is only for yield and area whereas the key impacts on livestock will come from other climate change factors, in particular droughts, floods and diseases. Those estimates must therefore be interpreted carefully.

Agricultural exports are a key area of concern**.** Significant impacts on the Arabica coffee growing area to 2050 are predicted due to climate change. These will have major implications for production and export value particularly in the Eastern region. There are also significant impacts predicted in the Robusta coffee growing regions elsewhere although the research is much less developed than for Arabica coffee. Climate induced yield losses for coffee could be in the order of 50-75% by 2050, as a result of a combination of yield reductions and (more importantly) loss of areas where coffee can be grown. These would represent a major impact on the economy, which is currently deriving 18% of its export earnings from coffee. Estimates of impacts on tea growing areas also indicate significant losses. Estimates consider a 50% fall in production by 2050 as plausible. Finally the IFPRI modelling shows some potential losses of cotton production due to yield impacts in the range of 60-77% of the no climate change scenario by 2050. Taken together these results indicate the potential for Ugandan agricultural export production and value to be strongly hit by climate change in the period to 2050 in the absence of adaptation actions.

Extreme events: It is widely accepted that extreme weather events have been increasing and becoming more severe in recent years and the analysis by Rautenbach (2014) concludes that these risks are likely to increase in the future in large parts of Uganda. To give an indication of the order of magnitude of recent losses, the damage figure of US$47million to crops (given in NEMA, 2008) is equal to about 3 per cent[15] of the value of all cash and food crops in 2008. Other extreme events have resulted in even bigger losses, possibly as much as 30 percent of the sector's normal output.

[15] Calculation based on GDP data for the agricultural sector in 2008 in UBOS (2013).

It appears therefore that the threat from droughts and floods is more important than the threat from decreased yields. It is already present and needs urgent action, making it a priority in terms of adaptation. It should also be stressed that current and future increased risks from flooding and droughts are in areas of existing poverty and therefore these events have serious consequences for local economies and food security.

6.1.1.2. Priorities for Adaptation Actions

Table 6.1 presents costs assigned to agricultural sector for adaptation in the Uganda National Climate Change Strategy covering the next 15 years.

Table 6.1 Additional Costs for Implementing the National Climate Change Policy: Agricultural Sector Adaptation (from Uganda National Climate Change Draft Costed Implementation Strategy)

Sector/Priority	Total Additional Costs (US$) (15 years)	Time Frame		
		Short- term (US$) (1-5 years)	Medium-term (US$) (6-10 years)	Long-term (US$) (11-15 years)
Strategic interventions				
1. Promote and encourage highly adaptive and productive crop varieties and cultivars in drought-prone, flood-prone and rain-fed crop farming systems	28,089,981	9,190,868	7,053,019	11,846,095
2. Promote and encourage highly adaptive and productive livestock breeds	32,900,993	15,318,113	7,053,019	10,529,862
3. Promote and encourage conservation agriculture and ecologically compatible cropping systems to increase resilience to the impacts of climate change.	13,014,701	6,127,245	2,938,758	3,948,698
4. Promote sustainable management of rangelands and pastures through integrated rangeland management.	21,978,601	-	8,816,273	13,162,328
5. Promote irrigated agriculture by encouraging irrigation systems that use water sustainably	54,652,627	-	21,746,808	32,905,819
6. Promote and encourage agricultural diversification, and improved post-harvest handling, storage and value addition in order to mitigate rising climate related losses and to improve food security and household incomes.	29,535,563	13,786,301	5,877,516	9,871,746
7. Support community-based adaptation strategies through expanded extension services and improved systems for conveying timely climate information to rural populations for enhanced climate resilience of agricultural systems	11,482,890	4,595,434	2,938,758	3,948,698
8. Develop innovative insurance schemes (low-premium micro-insurance policies) and low-interest credit facilities to insure farmers against crop failure	105,442,110	49,017,960	56,424,150	105,442,110

and livestock loss due to droughts, pests, floods and other weather-related events				
	297,097,466	**98,035,920**	**112,848,300**	**86,213,246**

Source: MWE (2012)

In addition to the policies listed in Table 6.1 (and partly overlapping with them) a number of actions have been proposed.

For crop production UNDP (2013) has suggested the following:

- Agricultural Practices, e.g. Crop diversification , Intercropping , Testing drought- and pest-resistant varieties (The government has been conducting trials to develop drought-resistant varieties of maize and beans)
- Soil and Water Management, e.g. Mulching using maize stocks and banana fibres to cool the soil (coffee) , Building soil and water conservation structures
- Land-use Management, e.g. Encroaching on wetlands to plant quick-maturing crops
- Livelihood Diversification, e.g. Migration , Selling of charcoal and firewood
- Finance , e.g. loans to finance local responses
- Capacity Building and External Support, e.g. Providing agricultural advisory services
- Knowledge Management, Information and Communication**,** e.g. Using local indigenous knowledge to forecast changes in seasons

As far as export crops are concerned there is already some literature on adaptation options for coffee such as the Oxfam report (Jassogne et al 2013) which recommends intercropping bananas and coffee with banana which provide shade to reduce temperatures. A study by IITA estimates that intercropping trees and matooke with coffee can generate up to 50 percent in additional income without reducing coffee yields (USAID, 2013). Policies need to take into account that perennial crops such as coffee and matooke require a longer lead time to adapt to a changing climate. For coffee, it takes a number of years before changes made by farmers yield results. This has clear implication for timing of adaptation policies for coffee.

Coffee has a number of international initiatives to promote adaptation in the sector. Some focus on the farmers and their organisations and are more holistic in their strategies (AdapCC, innovations project) others are more technical or specific in approach (CafAdpt, index based insurance), or look to combine these approaches (coffee under pressure). Although initiatives to promote the principles of sustainable production are an essential pre-requisite to achieve adaptation to climate change, they are not a sufficient response to the magnitude of impacts that are expected (Haggar & Schepp, 2012).

Finally for Extreme Events, in addition to the innovative insurance schemes mentioned in Table 6.1, evidence shows that the use of weather and climate information will reduce the agricultural losses and vulnerability of the rural poor. At least 10 percent of these losses could have been avoided by proper use of weather and climate information (UNEP/UNDP, 2009). The Uganda National Climate Change Draft Costed Implementation Strategy does have warning and information systems in its plan under Disaster Risk Management, but the imperative here is to tailor them to farmers needs and ensure that those in the agriculture sector who depend most on the information receive it in a time manner.

These actions are all relevant and appropriate for the agricultural sector to adapt to climate change. The problem is to evaluate them. This has to be done in a local context, where it is necessary: (a) to design the programme and estimate the costs and (b) compare them *ex ante* to what the likely benefits will be. The latter requires, first that some specific indicators be established to track possible progress from the measure and second that estimates be made of the likely changes in these indicators. Once they are implemented progress would then be monitored and the information gained used to modify existing measures and develop new actions in the future.

As the above steps need to be taken at the local level, where the adaptation actions will be implemented, a quantitative evaluation of the options will be proposed in case studies that must be implemented under this Economic Assessment of the Impacts of Climate Change in Uganda, in particular the case-studies in Karamoja and Mount Elgon regions.

At this stage only a qualitative assessment is possible, in which we use the results of the study to review how the measures, if implemented effectively, would: (i) contribute to alleviating particular negative impacts of climate change and variability, (ii) have a role in addressing the adaptation deficit, in mainstreaming adaptation. Finally we make a judgemental evaluation of the likely benefits relative to costs. The actions are presented in the form of "adaptation signatures", indicating those that address current problems or early priorities and those that may be necessary in the medium term and longer term actions. Where relevant we also identify critical decision points in implementing these policies and measures.

Table 6.2 provides a summary analysis and ranking of the strategic interventions proposed in the National Climate Change Costed Implementation Strategy. The main points that emerge are:

A. In almost all cases the proposed measures deal with current climate variability and can be justified in economic terms on those grounds. Hence they are part of addressing the adaptation deficit and if implemented effectively should provide benefits irrespective of future climatic change.
B. Most of those adaptation actions that have medium to long term benefits need to be initiated now because it will take time to test pilot versions and develop programmes that are robust.
C. Evidence from the existing literature and from this study suggests that the benefits of many of the proposed measures are potentially high relative to the costs. This is true for example for items 1-3, 6 and 7 in Table 6.1. In the case of item 4 (sustainable management of rangelands and pastures) the benefits from a climate viewpoint are less studied. In the case of items 5 (irrigated agriculture) and item 8 (insurance schemes), studies point to the great importance to ensure that the environmental context is right and that the economic support takes account of issues relating to sustainability and affordability.
D. In terms of timing items 3-8 in Table 6.1 could yield some benefits in the short to medium term, making them more urgent in terms of implementation. Items 1-2 have a somewhat longer perspective.

Of course in no case is the evidence from other studies a guarantee that the implementation of the measures in Uganda will be successful and cost effective. The programme needs to be evaluated at the national level on a case by case basis and implementation has to be technically and economically efficient. However, what the table does provide is an indication that in most cases the elements in the programme are on the right course.

Table 6.2: Priorities for Adaptation in Agriculture

Strategic interventions from the Costed Implementation Strategy	Impacts	Critical Dates/ Regions/Crops	Addresses adaptation deficit?	Mainstreams adaptation?	Likely benefits relative to costs and evidence from this and other studies
Short term priorities where considerable work has been done to implement major adaptation programmes					
7. Support community-based adaptation strategies through expanded extension services and improved systems for conveying timely climate information to rural populations for enhanced climate resilience of agricultural systems	Improved autonomous adaptation in the face of climate variability and change	This is needed urgently and should be introduced as soon as possible in all regions.	Yes. Information needs are high even now.	Yes. It makes climate concerns a part of the agricultural support programme.	Benefits of better information to farmers are found to be very high in many studies. At least 10% of losses could have been avoided by proper use of weather and climate information. Imperative is to tailor information to farmers needs and ensure that those in the agriculture sector who depend most on the information receive it in a time manner. IPCC, 2014, UNEP/UNDP, 2009.
6. Promote and encourage agricultural diversification, and improved post-harvest handling, storage and value addition in order to mitigate rising climate related losses and to improve food security and household incomes.	Stabilisation of incomes under climate variability and change.	Drought resistant maize & beans under trial. Mulching with maize stocks & banana fibres to cool soil in coffee growing areas.	Yes. These are issues that need to be addressed with current climate variability.	Yes. Adaptation for climatic reasons is made a part of the sustainable agriculture strategy.	Benefits of diversification are well documented. As long as programmes use resources carefully and efficiently the potential is there for a high benefit to cost ratio. (IPCC, 2014), Lin (2011).
8. Develop innovative insurance schemes (low-premium micro-insurance policies) and low-interest credit facilities to insure farmers against crop failure and livestock loss due to droughts, pests, floods and	Access to insurance avoids farmers adopting: low return/ low-risk practices, low application of inputs like fertilizer, lower adoption of new technologies and investments	Expand index based insurance programme for coffee (CafAdpt,) and other export crops	Yes. These are issues that need to be addressed with current climate variability.	Yes. It makes adaptation a part of the agricultural support strategy.	The evidence indicates that insurance schemes can have significant benefits if adopted. The problem is affordability for many poor farmers. If the programme can provide subsidies on a sustainable basis it should yield high benefits relative to costs. (Haggar & Schepp, 2012).

other weather-related events					
3. Promote and encourage climate smart agriculture (CSA) and ecologically compatible cropping systems to increase resilience to the impacts of climate change.	Less impacts on ecosystems and increased resilience to climate variability	Could have some short term benefits but more in the medium to long term.	Yes. Main benefits will be to climate variability	Yes. Unsustainable agricultural practices need to be addressed and this mainstreams adaptation as an element in the program.	Benefits of crop diversification have been estimated as significant. Lin. 2011. Case study in the Mt Elgon Region shows significant benefits if CSA is adopted soon for coffee there.
4. Promote sustainable management of rangelands and pastures through integrated rangeland management.	Benefits are improved livestock productivity irrespective of climate change. Climate benefits will be related to management under extreme conditions	Benefits could be realised in the short to medium term	Yes it mainly deals with the adaptation deficit.	Sustainable management of rangelands and pastures is part of sustainable agriculture	Benefits relative to costs with respect to climate have been little studied but case study in Karamoja region
Medium to long term priorities where further work is needed					
2. Promote and encourage highly adaptive and productive livestock breeds	Climatic impacts on livestock are expected to be quite small so main benefits are to address climate variability and water demand in droughts	Benefits will be felt in the medium term but programmes need to start now.	Main benefit is to address the adaptation deficit, as livestock need to adapt now to climate variability	Yes. Productivity in the sector is low and improvements are needed	Combined adaptations involving crops and livestock can have high benefits relative to costs IPCC 2014, Chapter 7. Moore and Gharamani, 2013. In general there is less data for livestock than for crops.
5. Promote irrigated agriculture by encouraging irrigation systems that use water sustainably.	Increased yields not linked to climate change. Climate impacts depend on adequate investment in water storage	Water supply assessment under climate change is needed as a prior.	Yes, if it is recognizes environmental and economic constraints.	If irrigation programs take account of changing water availability then yes.	Irrigation is seen as an adaptation measure but it has to take account of water availability and adequate storage of water. IPCC 2014.
1. Promote & encourage highly adaptive & productive crop varieties and cultivars in drought-	Reductions in losses during droughts and floods.	Benefits will be felt in the medium term but programmes	Yes, the problem is already severe	Yes. Agricultural policy faces problems of dealing with extreme event losses and these	Evidence suggest that the benefits of both R&D in climate resilient varieties and their adoption can be very high. This includes crop diversification. Agarwala and Fankhauser, 2008. Lin, 2011

prone, flood-prone and rain-fed farming systems	need to start now.	measures will directly address them.

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ANNEX 1: ASSESSMENT OF IMPACTS OF CLIMATE CHANGE ON FOOD CROPS AND LIVESTOCK

The overall aim of the economic assessment of impacts of climate change on food crops and livestock was to estimate possible future losses to these outputs and to the economic value of the outputs due to climate change scenarios compared to a no climate change scenario. The estimated value of losses can be expected to vary according to the different climate scenarios, socio economic scenarios and price projections used. This approach therefore allows a comparison of the impacts on the agricultural sector of different scenarios and indicates if there are potentially significant losses for certain products.

Climate change can potentially impact agricultural production by: (i) reducing the area suitable for agriculture, (ii) altering the length of the growing season, (iii) reducing the yield potential, (iv) increasing the frequency and severity of extreme events (in particular droughts and floods) and (v) increasing the incidence of plant diseases (World Bank, 2013).

A literature review was carried out on available studies on these impacts in Uganda and in the wider region of Sub Saharan Africa (this is reported in detail in Annex 3). It was concluded that a number of research studies have analysed impacts on crop yield in Sub Saharan and East Africa including some for Uganda. Results are available for key crops produced in Uganda including maize, millet, sorghum, beans, rice and groundnuts. However, in most cases there is a large range in yield impact findings and in many cases these are taken from generic estimates for the region. Climate change impacts on agricultural production other than on yield potential are less well reported in the reviewed studies. Changes in the area suitable for crops are covered to some extent (including in the IFPRI modelling of production changes in East Africa reported in Waithaka et al.,2012) but there is limited detailed quantitative analysis on the impact on future production of extreme events (see Section 5) and plant diseases. Much less research has been published on the effects of climate change on livestock than on crops and there are apparent inconsistencies in the findings of available studies (World Bank, 2013).

The modelling of climate change impacts on agriculture in Uganda by the International Food Policy Research Institute's (IFPRI) reported in the Bashaasha et al (2012), study following the methodology of the global analysis of impacts in Nelson et al 2009, 2010a and 2010b, has been used as a key source for the analysis of food crops and livestock for Uganda reported in this section. This advantage of using the IFPRI datasets for the economic assessment is that they: (i) cover a wide range of food crops and livestock in Uganda, (ii) use a consistent methodology which allows direct comparison of impacts between specific crops and livestock products and (iii) include impacts on future production from changes in both yields and suitable area. The project team were also greatly assisted by being given access to unpublished and updated results from the IMPACT[16] modeling of climate change effects by IFPRI. This allowed much more detailed and methodologically consistent analysis of emission scenarios and socio economic scenarios for different agricultural products than would otherwise have been possible using ad hoc results for crops and livestock from a range of research studies.

[16] International Model for Policy Analysis of Agricultural Commodities and Trade

The analytical framework used in this analysis integrates three models used: (i) IFPRI's International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) Spatial Production Allocation Model (SPAM); and the Decision Support Software for Agrotechnology Transfer (DSSAT) crop model suite that estimates yields of crops in varying management systems and climate change scenarios [17]. As such this methodology takes a generally top down approach in the estimation of impacts on yields. It should also, be noted that the IFPRI modeling used, and at present continues to use, the IPCC fourth assessment report (AR4) SRES emissions scenarios rather than the Representative Concentration Pathways (RCPs) of the fifth Assessment report (AR5) as used in the Rautenbach (2014) study. This is also the case for the key studies on yield impacts of climate change reviewed for this project (see Annex 3). The AR4 lower emissions scenario B1 used in IFPRI modelling is closest to RCP4.5 scenario used in Rautenbach (2014) and the AR4 higher emissions scenarios A1B used in IFPRI modelling is closest to RCP6 which is not used by Rautenbach. The more extreme higher emissions scenario RCP8.5 used in Rautenbach is closest to the AR4 emissions scenarios A1FI which has not been used in the IFPRI modelling.

Using datasets from the IFPRI modeling we have undertaken a national level analysis of impacts on key crops and products and also made some assessment of impacts at the regional level.

National Level Analysis of Crops and Livestock

The national level analysis covers climate change impacts on production and value of 14 crop products and 6 livestock products in Uganda for which IMPACT data are available. Some products such as export crops, bananas and simsim are not available in the IMPACT data. Available estimates of production to 2050 for each product include changes to both yield and cultivation area due to climate change. Growth in productivity such as through technological improvements is also taken into account.

Results are available from the IMPACT modelling for impacts under both the CSIRO climate model and MIROC climate models[18] For each model, projections were made for agricultural production under:

- **Emissions scenarios** A1B (higher emissions scenario), B1 (lower emissions scenario), and for a no climate change scenario.
- **Global socio economic scenarios** defined according to GDP and population growth (pessimistic, baseline and optimistic). Table A1.1 summarises the projections used in these scenarios.

Table A1.1: Summary of population and per capita gross domestic projections, 2010 and 2050

	2010	2050		
East Africa		**Pessimistic**	**Baseline**	**Optimistic**
Population (m)	361.1	879.4	777.1	681.6
Income per capita (2000 US$)	204	565	1,161	1,778

Source: Waithaka, M. et al.(Eds) (2012)

[17] A detailed technical explanation of the methodology used by IFPRI can be found in chapter 2 of Waithaka et al.(2012).

[18] CSIRO = climate model developed at the Australia Commonwealth Scientific and Industrial Research Organisation; MIROC = Model for Interdisciplinary Research on Climate, developed by the University of Tokyo Center for Climate System Research.

A summary of crop production projections from IFPRI modelling for 11 Crops in 2050 for the scenarios explained above is given in Figure A1.1. The key comparison to note here is between production in the climate change scenarios for different models and the no climate change scenario (the right hand set of columns for each crop). Figure A1.2 presents production in the climate change scenarios as a percentage of production without climate change in 2050. For some crops there is clearly lower production under climate change scenarios than no climate change (e.g. cassava, potato, sweet potato). In other cases the difference is more marginal (e.g. millet, sorghum). In some cases whether production is lower or higher under CC depends on which model and scenario you choose , for example, in the case of maize, production is lower under climate change for all scenarios except the MIROC A1 scenario. Note also that total production is growing under all scenarios to 2050 but most climate change scenarios will lessen the extent of that growth, for example maize production in 2013 was about 2.7 million tonnes whereas under all modelled scenarios production is over 3.5 million tonnes in 2050.

We cannot make a direct comparison between these results and the findings from other studies on climate change impacts on crop yields in the region reviewed in Annex 3 due to the range of different bases and geographical resolutions of the estimates. In the case of maize almost all the reviewed studies show a negative impact on yield to 2050 and beyond ranging from a mean decline for Uganda of 18 percent (Schlenker & Lobell, 2010) to a decline in the range of 4.6 to 0.8 percent (Nelson et al, 2010b). Millet is also projected to have negative yield impacts of 6 to 7 percent by mid century (Berg, et al, 2012) while Wasige (2009) projections some declines in yield for most of the agro-ecological zones in Uganda. Sorghum is an interesting case as the Wasige (2009) study concludes that under the climate scenarios used the yield will be higher for most areas of Uganda and therefore it could be seen as an adaptation crop. However, this conclusion differs from the range of yield declines of 0 to -10% for sorghum given in Schlenker & Lobell (2010).

A summary of livestock product projections in 2050 for the scenarios given above is shown in Figure A1.3. This shows that in all cases there are not significant differences between production in the climate change scenarios for different models and the no climate change scenario. This is an interesting finding in that it suggests that changes in overall trends in precipitation and temperature will not result in great impacts on the yield of livestock and that the key climate change impacts to focus on may be those from droughts and floods. This conclusion should, however, be treated with caution given the relative lack of clear results from other studies on this subject (see Annex 3). It does nevertheless concur to some extent with findings from Seo et al (2008) that suggested that warming is likely to increase livestock income in some other parts of Sub-Saharan Africa unless there are large increases in temperature.

Figure A1.1: Overview of Crop Production Projections for 11 Crops (Total production in 2050, 1000 tonnes)

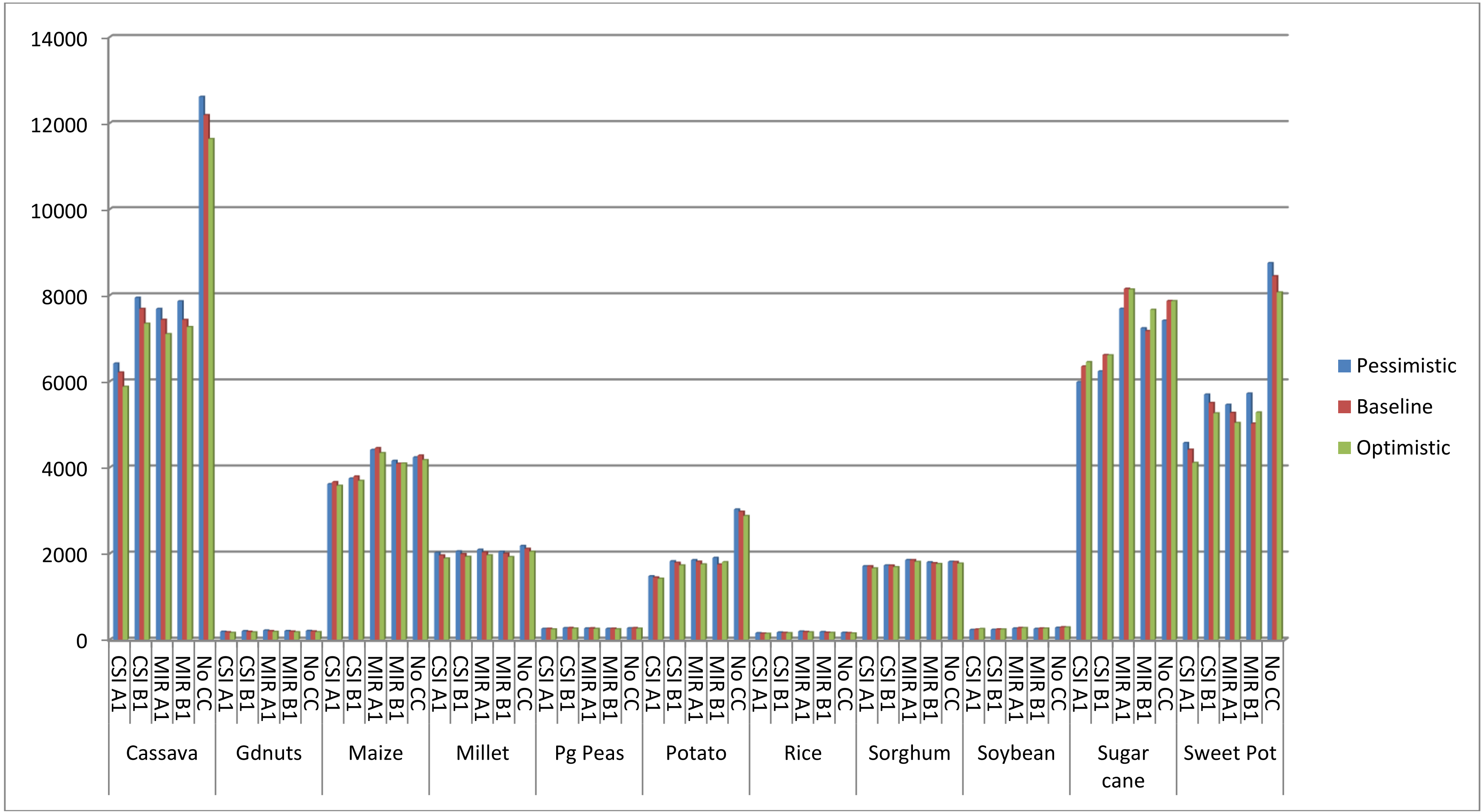


Figure A1.2: Climate change scenario production as a percentage of production without climate change in 2050 (%)

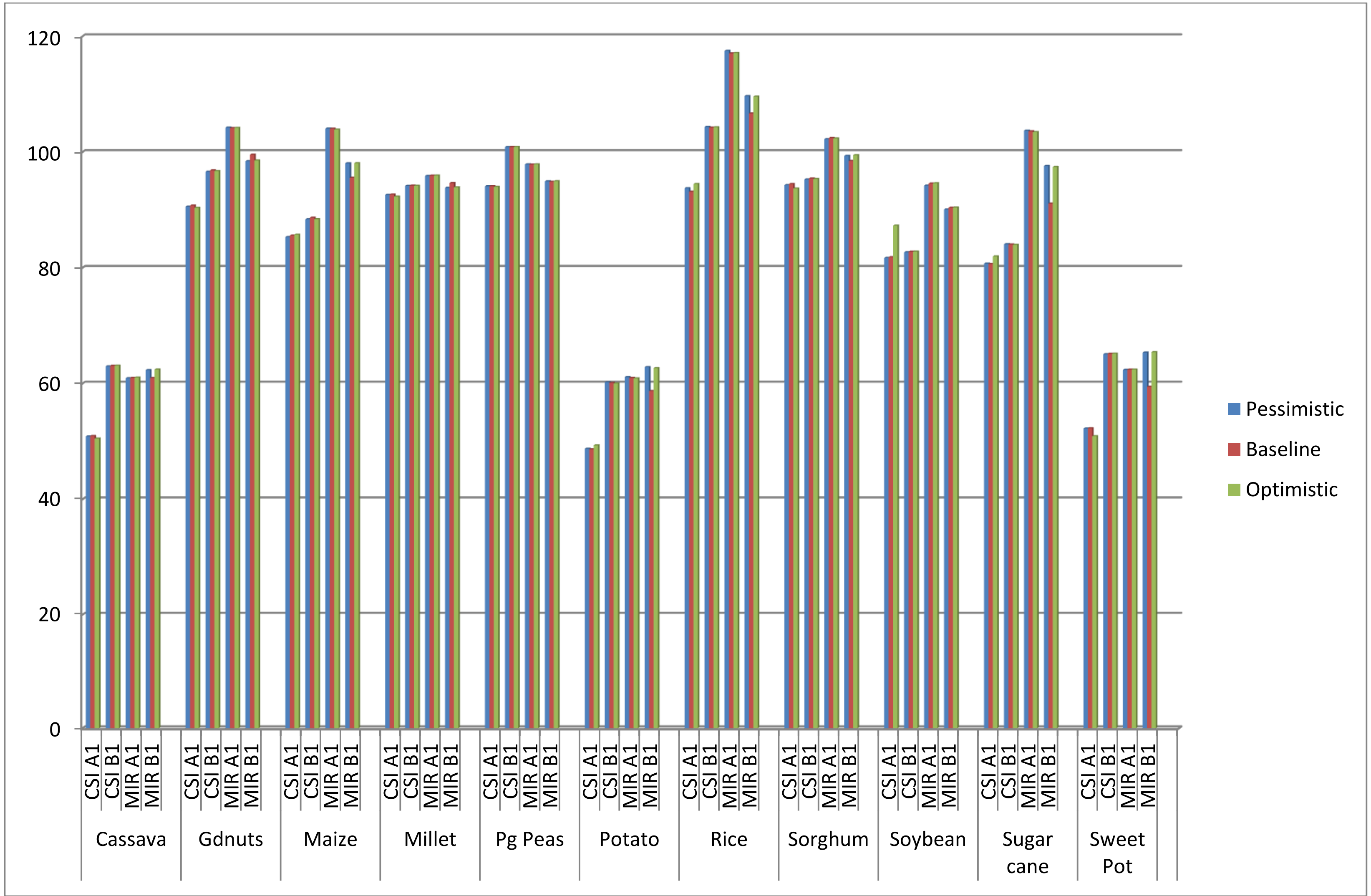
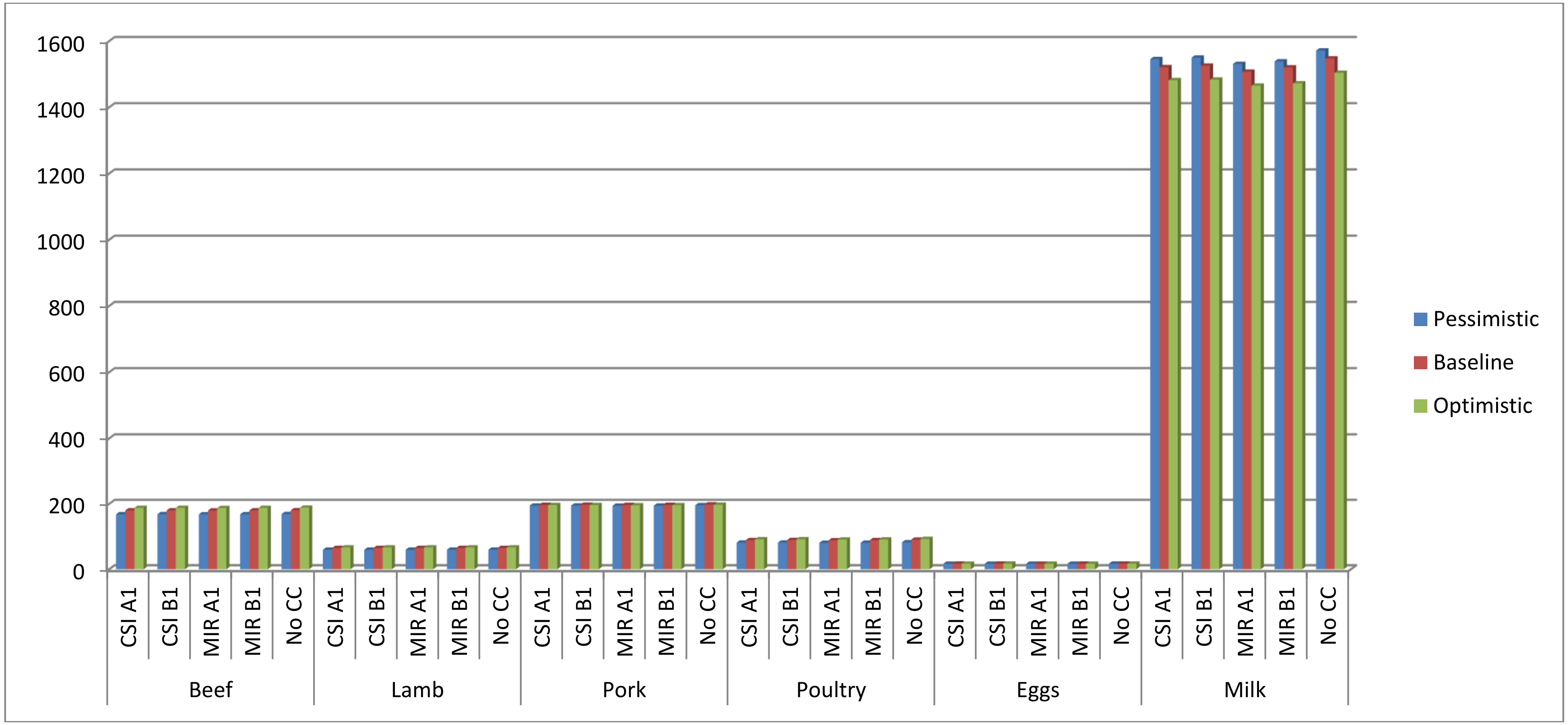


Figure A1.3: Overview of Livestock Production Projections (Total production in 2050, 1000 tonnes)



Based on: (i) the production estimates for each emission scenario and global socio economic scenario for each product summarised above and (ii) price data provided by IFPRI for each scenario and product, we have calculated the following:

(i) ***Total value of production in 2050 for each product under each scenario***. Figure A1.4 shows the summary results for these estimates for 11 crops. Figure A1.5 is based on the same data but highlights the difference in value between (i) the various emissions and global socio economic scenarios for each product in 2050 and (ii) the no Climate change scenario in 2050. Thus negative values beneath the x-axis represent a decrease in value under climate change and positive values above the x-axis represent an increase in value under climate change.

It is noticeable that some crops clearly lose significant value under climate change scenarios to 2050 including sweet potato, potato and cassava. In other cases there are overall gains in value under climate change scenarios such as for maize and sorghum. And in other cases both gains and losses are estimated according to the climate model such as for sugar cane.

It is important to bear in mind that the estimates of value changes are very dependent on price projections to 2050 modelled by IFPRI. For example, since production of maize is projected to be lower in 2050 under most climate change scenarios than without climate change (see Figure A1.1) the gains in value of maize shown in 2050 under climate change scenarios (Figure A1.5) are entirely due to much higher projected prices for maize compared with prices without climate change.

It should be noted that, according to the Agricultural Census of 2008/9, a high percentage of crop production is not sold at market but consumed or stored. For example, only 40 percent of maize was sold in 2008/9. Therefore, the estimates of climate change impacts on value represent the change in total value of production whether sold or not.

(ii) ***Change in net income in 2050 for each product due to climate change scenarios.*** This is shown in Figure A1.6 and is based on the above estimates of difference in value between climate change scenarios for each product and the no climate change scenario. It was calculated using data on the typical percentages of gross margin in total revenue for each product from the IFPRI Enterprise Survey undertaken in Uganda (IFPRI, 2010). For some products where we do not have gross margin data we have assumed 25 percent.

A significant caveat here is that these estimates are likely to overestimate real changes in the net income of farmers because (i) much of the production of food crops by farmers is for family and local consumption and is not sold and (ii) the international prices used in the estimates of net income changes may not be representative of the local market price for some crops.

Figure A1.4: Overview of total value of projections for 11 Crops in 2050 (USD 1000 at 2000 prices)

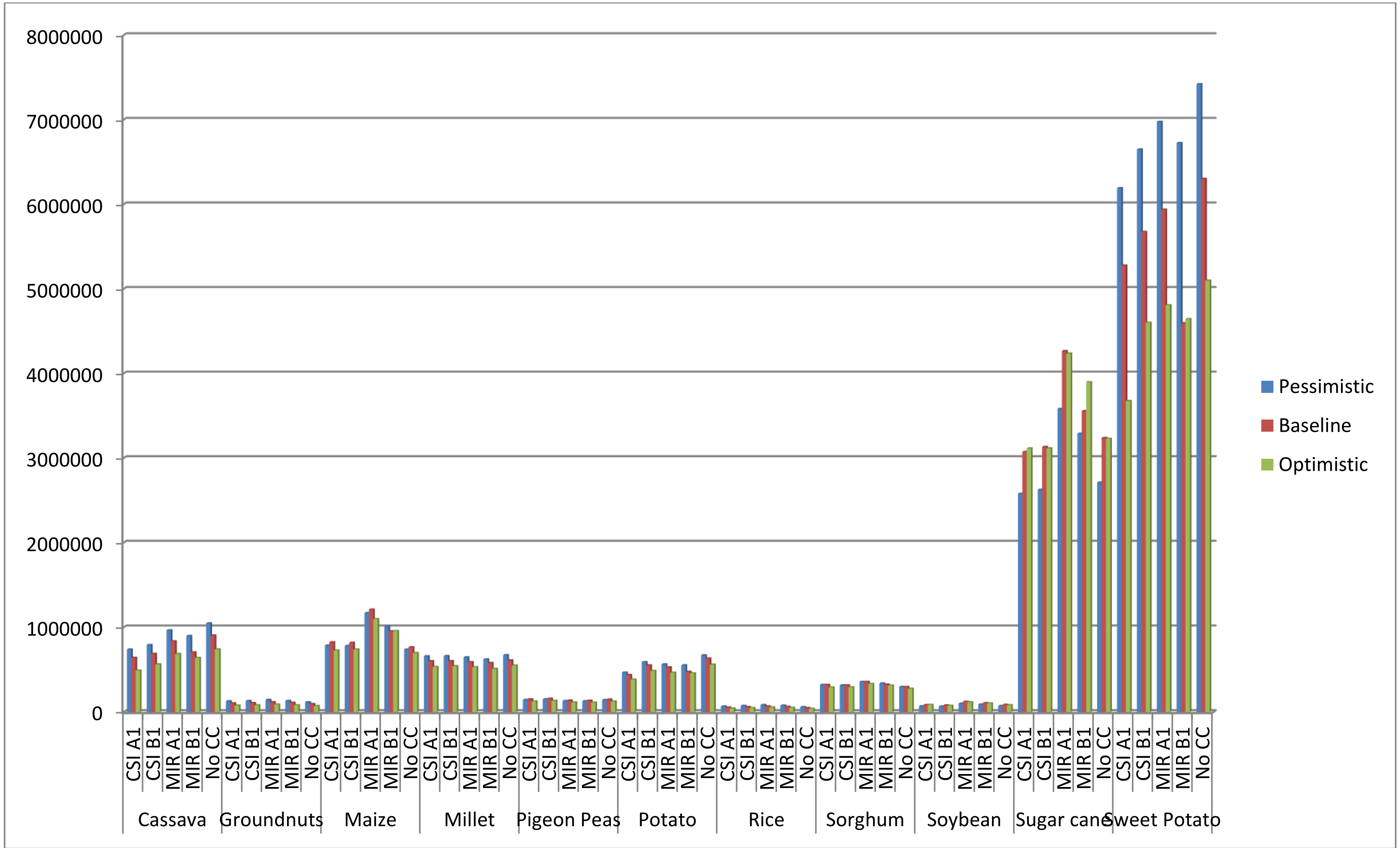


Figure A1.5: Value Change due to Climate Change compared with no Climate Change in 2050 (USD 1000 at 2000 prices)

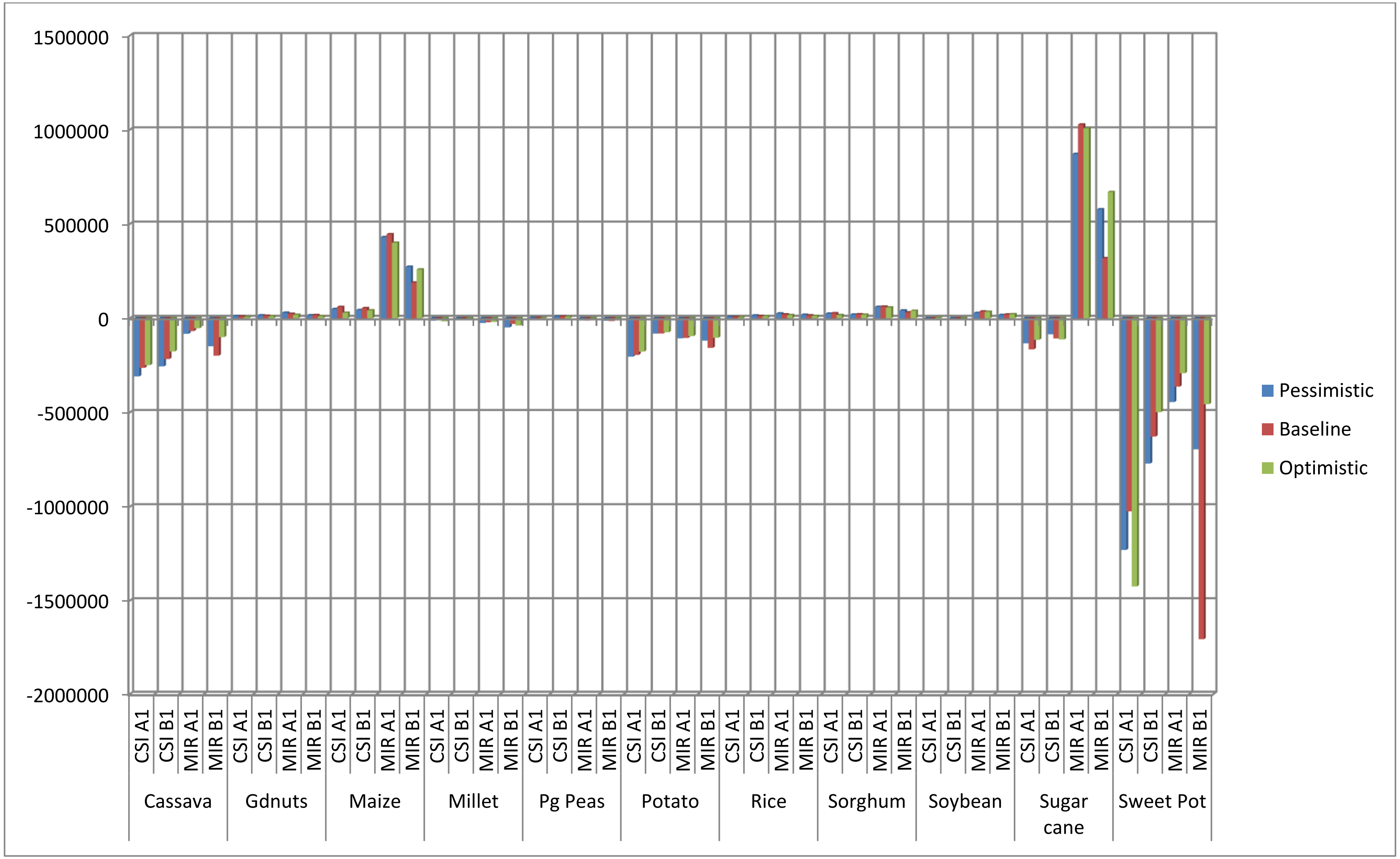
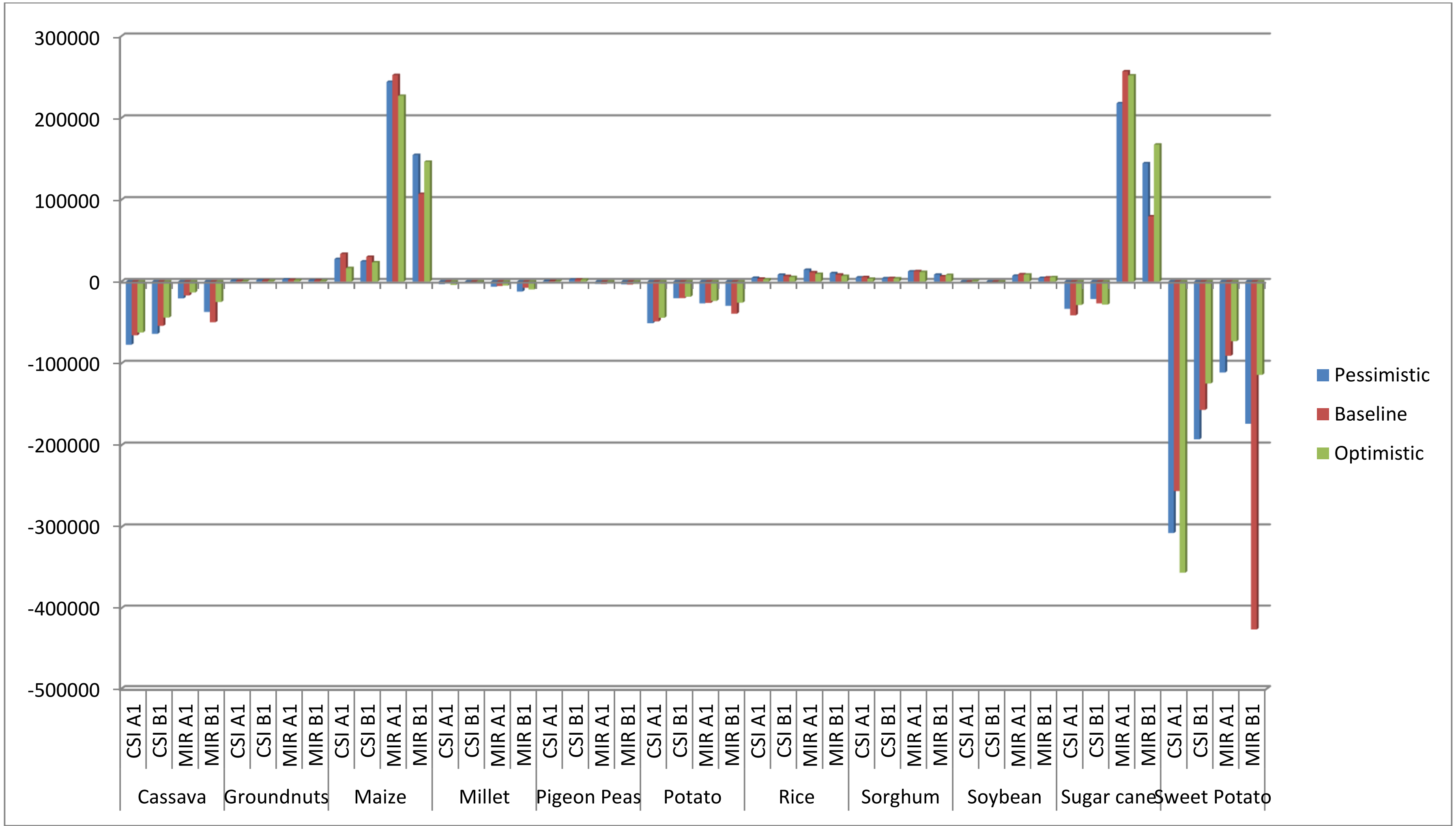


Figure A1.6: Change in net income due to Climate Change compared with no Climate Change in 2050 (USD 1000 at 2000 prices)



Regional Level Analysis of Selected Crops

To further inform the national level assessment regional level analysis of climate change impacts on production and value has been undertaken for four key crops in Uganda. These results have been calculated based on unpublished district level yield change estimates for maize, sorghum, soybean, and rice (Rainfed and Irrigated) to 2050 provided by IFPRI. These estimates are from four climate models for the A1B emissions scenario only[19]. The models are:

- CNRM-CM3 = National Meteorological Research Center–Climate Model 3;
- CSIRO = climate model developed at the Australia Commonwealth Scientific and Industrial Research Organisation;
- ECHAM 5 = fifth-generation climate model developed at the Max Planck Institute for Meteorology (Hamburg); GCM = general circulation model;
- MIROC = Model for Interdisciplinary Research on Climate, developed by the University of Tokyo Center for Climate System Research.

The estimated district yield change percentages have been aggregated at the level of the four regions of Uganda (Central, North, East and West) based on a weighted average of harvested area for each district[20]. Table A1.2 shows these average yield change percentages per region for the four climate models. This it stressed that this is an approximation due to a mismatch between districts used in IFPRI yield change results and official districts of Uganda. This is due to complex changes over time in the official number and boundaries of districts and a disconnect between the mapping used and these official boundaries. Despite this caveat, the table illustrates the differences in estimates produced by the four models and the differences in estimated yield changes between regions with, in general, the Eastern and Northern regions estimated to experience the larger impacts.

Table A1.2 Estimated average yield change due to climate change (2000 to 2050) per Region (%)

Region	CNRM A1	CSIRO A1	ECHAM A1	MIROC A1
Maize				
C	-7.9	-0.2	-2.6	2.2
E	-12.0	6.5	5.0	7.4
N	-12.2	-14.4	-8.7	11.9
W	-2.6	-3.5	-16.2	7.6
Sorghum				
C	-1.5	3.5	4.3	10.3
E	-15.9	-2.9	-13.3	-4.5
N	-17.5	-11.4	-14.2	1.6
W	8.4	-3.4	61.6	13.5
Rice RF				
C	6.1	9.5	12.5	15.9

[19] The IFPRI district level results are only available for the SRES A1B greenhouse gas emissions scenario that assumes fast economic growth, a population that peaks midcentury, and the development of new and efficient technologies, along with a balanced use of energy sources.

[20] Harvested area is based on estimations from the Spatial Production Allocation Model (SPAM 2000)

E	-7.9	0.5	0.1	-0.7
N	-20.7	-7.0	-6.3	12.0
W	23.9	13.0	39.6	23.8
Soybean				
C	-24.6	-12.3	-19.2	-14.9
E	-20.7	-4.4	-18.1	-9.0
N	-24.1	-8.4	-16.4	-9.2
W	-16.7	-9.2	-19.4	-7.8

Source: Calculated from IFPRI data

Based on these yield change estimates we have made estimates for regional production changes to 2050 due to climate change. Baseline regional production data for each crop has been taken from the Uganda Census of Agriculture 2008/2009 (UBOS, 2010). Figure A1.7 gives the estimated percentage of production difference due to climate change compared with no climate change scenario in 2050 per region. This assumes an annual percentage crop production increase of 1.9 per cent per annum based on projections for Sub Saharan Africa from the FAO report World Production Towards 2030/50 (Alexandratos & Bruinsma , 2012).

Based on the above production estimates, estimates for value changes to 2050 due to climate change were made based on market prices in Uganda supplied by local consultants. Figure A1.8 shows the estimated percentage of value difference due to climate change compared with no climate change scenario in 2050 per region. This uses current prices and therefore does not assume any price changes to 2050.

Figure A1.7: Estimated production difference due to climate change compared with no climate change scenario in 2050 per region (%)

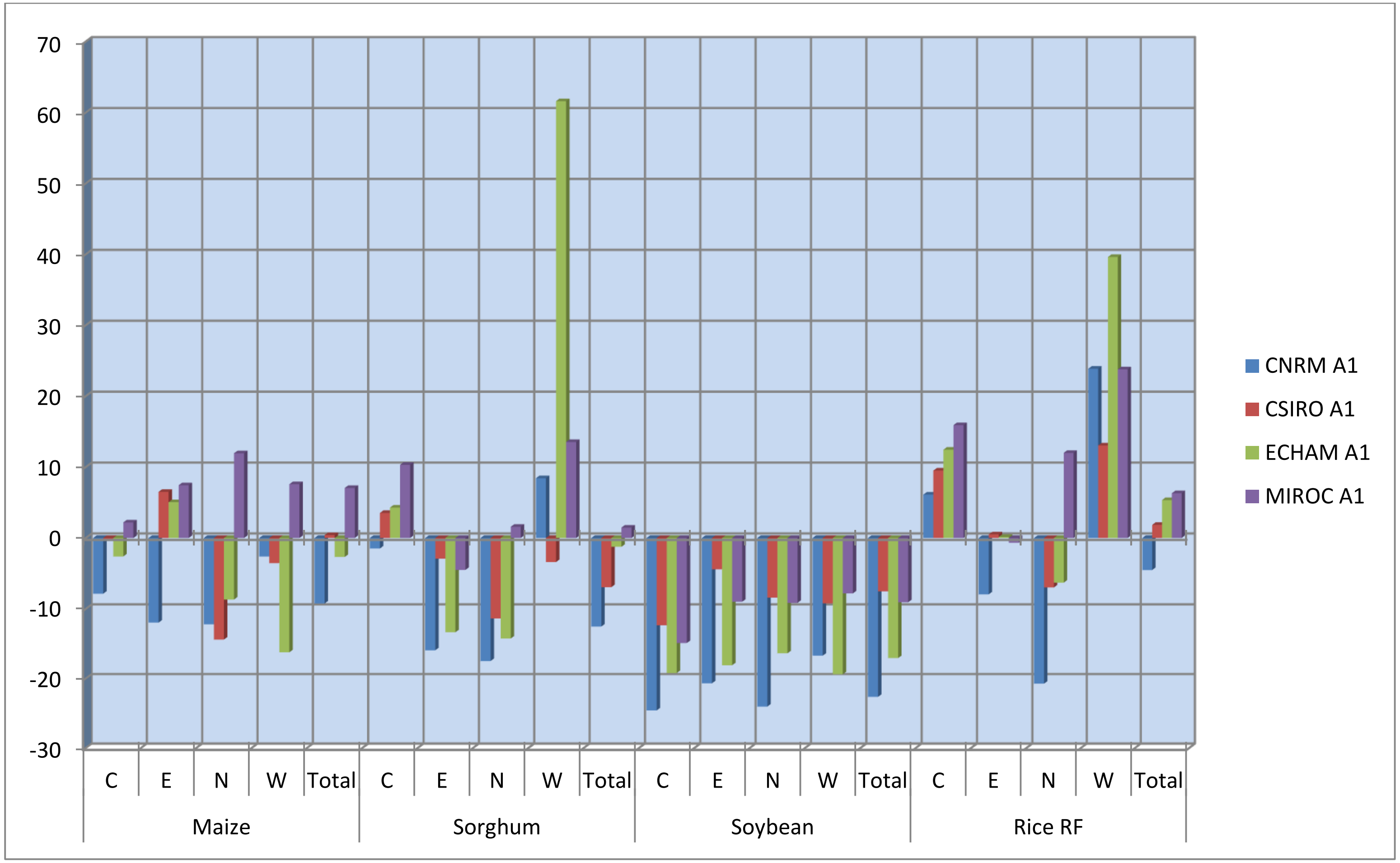
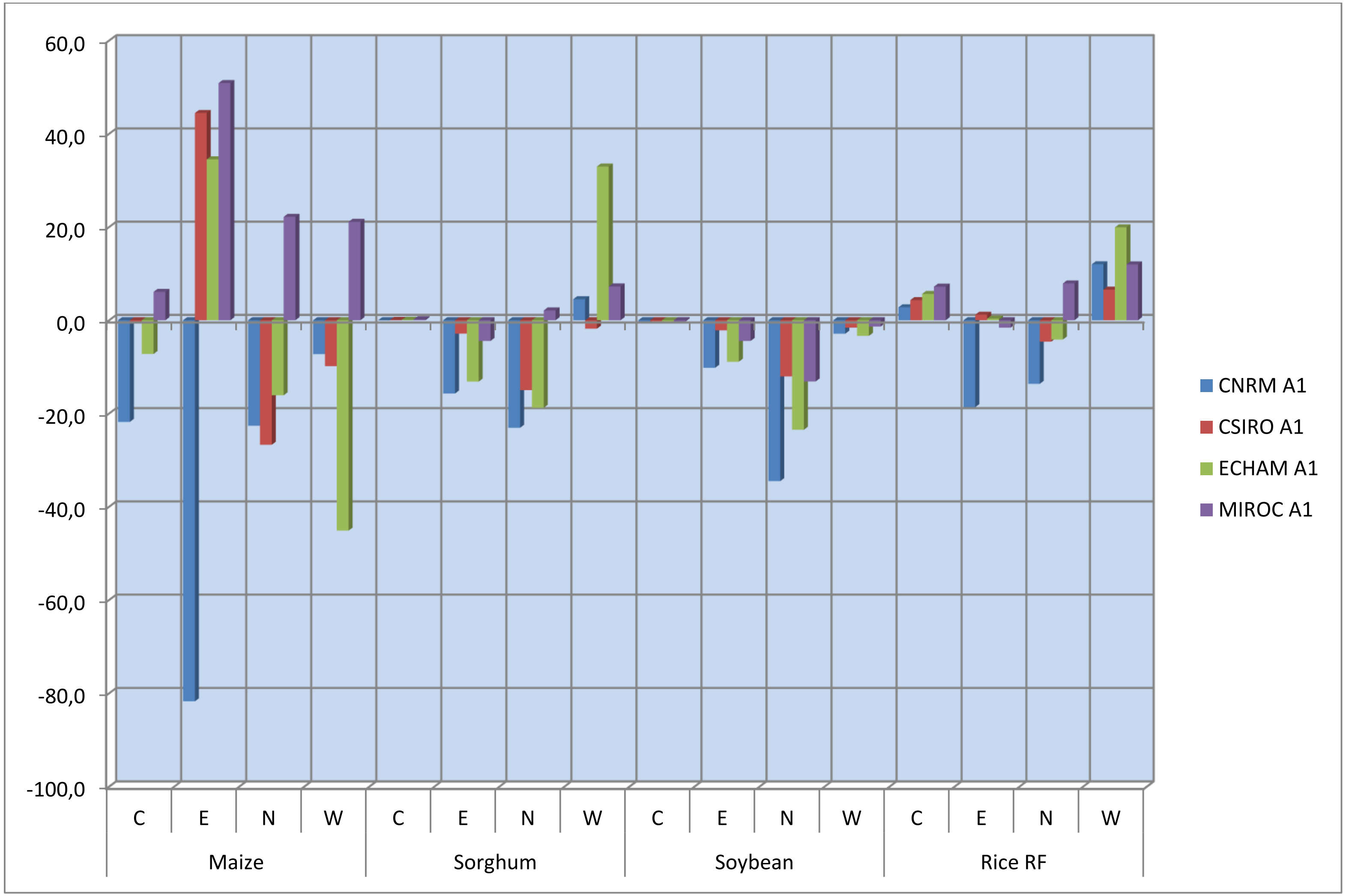


Figure A1.8: Estimated value difference due to climate change compared with no climate change scenario in 2050 per region (%)



ANNEX 2: ASSESSMENT OF IMPACTS OF CLIMATE CHANGE ON AGRICULTURAL EXPORTS

The agriculture sector contributes significantly to total exports in Uganda with the "food, animals, beverages, tobacco" category being the largest commodity group for exports in 2013 representing 49.9 per cent of total export value or about US$1200 million. This category of exports has seen an average growth rate from 2009 to 2013 of about 13 per cent[21]. Key export crops are coffee (the largest export commodity contributing about 18 percent to total export value in 2011 to 2013), tea (3.1 percent in 2012), cotton (3.2 percent in 2012) and tobacco (3 percent in 2012). Other significant crop exports are maize (2.4 percent), rice (1.6 percent), cocoa beans (1. 6 percent), cut flowers (1.1 percent), beans (0.6 percent) and sesame seeds (0.5 percent) (UBOS, 2013).

In this section we focus mainly on the potential impacts of climate change on production and exports of coffee with some discussion of tea and cotton. Our literature search for studies on climate change impacts on tobacco production did not provide information for Uganda that could be used as a basis for discussion of economic impacts. The economic impact on national production of maize, rice and sesame seed is discussed as part of the food crop analysis in Section 3 and concludes that under some climate scenarios there will be a reduction in production trends to 2050 for these crops and this will have implications for future export production and for prioritization of adaptation options.

Coffee Exports

Coffee is a key cash crop of Uganda. Total production was 186,126 tonnes in 2012 (FAOstat 2014) of which Arabica coffee was 53,404 tonnes and Robusta coffee 133,458 tonnes. Between 1998 and 2012 Robusta production represented between 71 percent and 89 percent of total production. The total production area was 285,000 ha in 2013 (UCDA)[22] (of which 22 percent was Arabica and 78 percent was Robusta) with the trend varying between a maximum of 345,000 ha in 2008 and minimum of 217,000 ha in 2002 (FAOstat 2014).

Robusta is grown extensively in a 300 km radius around Lake Victoria but also in other regions. Arabica is grown around Mount Elgon in the east, the mountain ranges in west-Nile and Mount Rwenzori in southwest Uganda. Table A2.1 shows hectares cultivated by region. The table also indicates the high numbers of households involved in cultivating coffee (over 500,000 for Arabica and nearly 1 million for Robusta).

Table A2.1: Summary of Coffee Cultivation Areas and Number of Households (2013)

	Hectares	% of Hectares	Number of Households
ARABICA			
W	9247	15	115451
E	36261	58	312509
N	9097	14	75735
SW	8199	13	63026
Total	62804	100	566721

[21] UN Comtrade, Uganda Overview: http://comtrade.un.org/pb/CountryPagesNew.aspx?y=2013
[22] Data provided by Uganda Coffee Development Authority

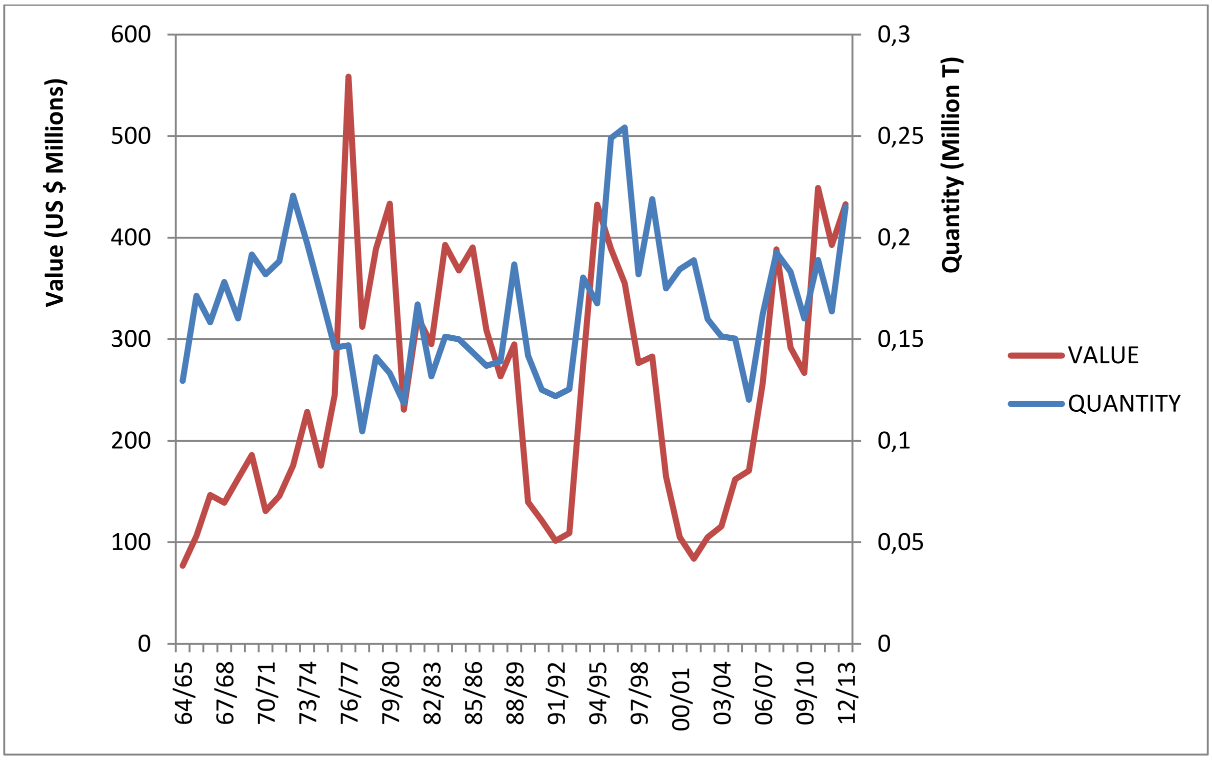
ROBUSTA			
W	43256	20	252746
E	21075	10	118627
N	11088	5	16970
C	122377	55	474901
SW	24024	11	133150
Total	221820	100	996394

Source: Adapted from data provided by Uganda Coffee Development Authority.

Prices data since 2008 (provided by Prof Bashaasha) shows that Arabica has generally had a higher price than Robusta, varying from parity to double the price. For example, in Sept 2012 Robusta (fair Quality) was 4,250 Shs/kg, Robusta (Kiboko) was 2,000 Shs/kg and Arabica was 4,400 Shs/kg (this is approximately 1657 US$/tonne Robusta (fair Quality), 780 US$/tonne Robusta (Kiboko) and 1716 US$/tonne for Arabica).

Total coffee exports were about 215,000 tonnes in 2012/13 with a total value of US$433m and a unit value of 2.01 USD kg (UCDA). This represented about 18 per cent of total exports from Uganda. Over the last 20 years the percentage of total Ugandan coffee production that is exported has been generally in the range 86% to 96% (calculated from FAOstat). Figure A2.1 shows the volatility of volume and value of coffee exports over recent decades.

Figure A2.1: Uganda Coffee Export Trends (Value and Quantity)



Source: Drawn from UCDA dataset

Climate Risks for Coffee Production

Coffee production globally is especially sensitive to climate variability and change. Both Robusta and Arabica coffee have high but different sensitivities to changing temperature and rainfall conditions. Optimal growing conditions for Robusta coffee require slightly higher temperatures and rainfall than Arabica and it is much less adaptable to lower temperatures than Arabica (Haggar & Schepp, 2012). Furthermore, floods and droughts can have direct impacts on coffee tree growth due to their shallow roots. During the 1997/1998 floods in Uganda, coffee exports dropped by 60 percent (UNDP 2013). In addition, increases in temperature are forecast to increase the development rates of pests such as the coffee berry borer in parts of East Africa (UNDP, 2013). A further factor that is not well understood is the response of coffee to increased carbon dioxide concentrations from climate change. This fertilisation effect may partially offset some of the negative consequences of changing temperature and rainfall.

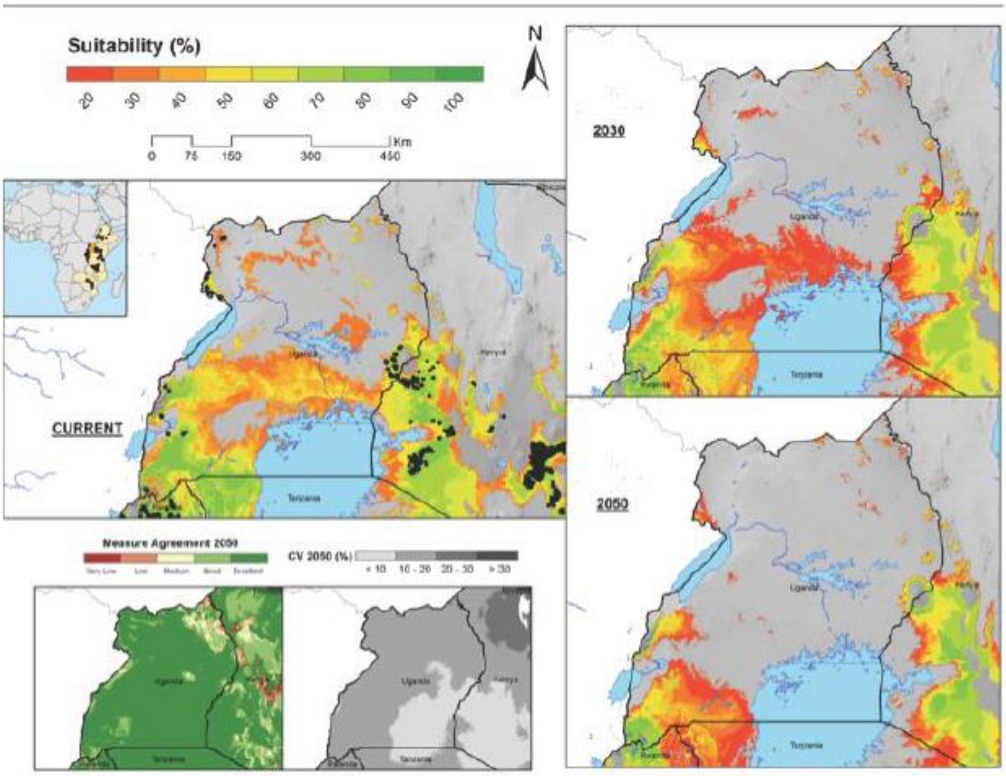
High fluctuations in coffee production in Uganda in the last 40 years have been mainly attributed to climate variability, along with other factors such as reduced soil fertility and mismanagement (UNDP, 2013). However, there is limited data to confirm a correlation between coffee production and climate change. It is important to note also that different varieties of Robusta and Arabica with different sensitivity to climate hazards are grown in different districts in Uganda. Thus for a fuller understanding of climate impacts in Uganda further research is needed through crop modelling based on the specific varieties grown in different districts.

Other local factors also influence the vulnerability of different coffee producing areas to climate change. These include land fragmentation, environmental degradation, soil fertility, incidence of pests and diseases, availability of storage facilities, the amount of post-harvest losses and levels of good management practice. The age of coffee plantations may also be in factor as most plantations in Uganda are over 20 years, increasing susceptibility to the negative impacts of climate variability and change (UNDP, 2013).

Most of the studies of projected impact of climate change on coffee in our literature review show consistently significant declines in areas suitable for cultivation under different emissions scenarios. For example, a significant global decrease in the range of about –7 to –15 percent in area suitable for coffee production by 2055 is forecast in Lane and Jarvis (2007). Most work has focused on Arabica with recent studies by CGIAR researchers using methodology based on the ecological niche concept[23]. Future suitability of growing areas were assessed using the results of 21 GCM models via the software MAXENT with analysis based on SRES-A2a, the IPCC business as usual scenario (CIAT, 2013; Läderach & van Asten 2012; and Jassogne, Läderach & Van Asten, 2013). Figure A2.2 gives the findings on suitability for production in Arabica producing regions in Uganda for the current period and predictions for 2030, and 2050. This shows a great reduction of areas most suitable for production by 2030 and a great loss of area suitable for coffee growing at all by 2050. It should be noted that the IPCC has criticized the ecological niche modelling approach as a basis of adaptation decision-making (See UNDP, 2013). However, in the absence of other such detailed climate impacts studies this is the best current analysis available.

[23] For fuller explanation of methodology based on the ecological niche concept and used for global tropical regions see Bunn et al (2013).

Figure A2.2: Predicted suitability for coffee production in Arabica coffee-producing area in Uganda (Current, 2030, and 2050).



The coefficient of variation (CV) and measure of agreement (ME) is shown for the study area with the points (black dots) representing the sampled *Coffea Arabica* farms (large map); adapted from Läderach and van Asten (2012).

The review by Haggar & Schepp (2012) concluded that findings from Uganda and Kenya suggest that climate change would result in the minimum altitude for Arabica production increasing by up to 400 metres and Robusta production moving to higher rainfall zones. Davis et al (2012) focuses on Arabica Coffee in Ethiopia but show dramatic declines in suitable growing areas consistent with those predicted for Uganda. Available studies do, however, indicate variations in their conclusions on the extent of loss of suitable growing area. For example, Nandozi (2012) estimates future suitability for coffee growing based on the projected climate to 2071-2100 and indicate that about 14 percent of the current coffee area is likely to be only marginally suitable and only 2 percent is likely to be completely unsuitable for coffee growth. This variation in findings indicates the great uncertainty of such estimates.

Much less work has been done on the impacts of climate change on Robusta even though this accounts for higher percentage of production than Arabica in Uganda. The most commonly cited forecast for Robusta is by Simonett (1989) which gives maps showing a drastic decline in suitable growing area in Uganda caused by a 2% rise in temperature. This was used as key evidence in the International Coffee Council report on climate change (ICC, 2009). However, the map was produced in 1989 and Haggar & Schepp (2012) conclude that "it is not clear what the scientific basis is of the prediction for Uganda, so any extrapolation must also be considered speculative." This underlines the need for further research in modelling of the impacts of climate change on Robusta coffee in particular.

Economic Impacts on Coffee from Climate Risks

In light of the research findings outlined above the impacts of climate change on the global coffee industry are potentially very significant. A reduction in areas suitable for cultivation of coffee globally will influence the world coffee market and increase pressure on prices. Greater concentration of production in remaining suitable areas may increase the risk of price volatility, for example, due to greater vulnerability of supply to extreme events (Haggar & Schepp, 2012). At the local level the impact may be severe for small-scale farmers in areas becoming less suitable for coffee as they are at risk of significant loses of yield and income (ICC, 2009).

A number of reports highlight the potential for significant future value losses for coffee production in Uganda. For example, climate-induced yield losses in the order of 10–50 percent, potentially reducing foreign exchange revenue by US$15–80m per year, are cited in the recent Oxfam Research Report (Jassogne et al, 2013). Another source suggests that a shift in the viability of coffee growing areas could potentially reduce export revenue by 40 percent (based on total 2012/3 export value of coffee this would amount to about US$173). However, there has not been a detailed economic analysis on the potential impacts of climate change and variability on coffee in Uganda.

For this project an assessment of potential loss of coffee production and export value has been made for Uganda by region. It is stressed that these results are not forecasts but are purely illustrative of the order of magnitude of economic impacts under different assumed scenarios of future yield, production and price.

Impacts on Production of Coffee

UCDA data for current cultivated area and number of trees by district/region for Arabica and Robusta was used to estimate coffee production by district/region. The estimates were based on apportioning the total production of Arabica and Robusta in 2012/13 (from USDA, 2013) to the districts and regions of Uganda according to the proportions of their number of trees to total number of trees from UCDA data[24]. While this does take into account differential production between Arabica and Robusta trees it assumes average production for Arabica trees and Robusta trees is constant between different districts and regions.

Current production data per region of Uganda were used to estimate impacts of climate change on production in 2050 under a number of scenarios. As discussed above, the studies on impacts of climate change on coffee show a consistent picture of declines in area suitable for coffee growing in Uganda but we do not have available estimates of how this may impact on production. The most detailed studies, reported in Läderach & van Asten (2012), gives geographical representation of predicted changes in suitability for Arabica coffee production (only for the SRES-A2a scenario) but this does not provide us with an appropriate dataset to make credible estimates of how these changes in areas of suitability will translate to changes in production potential at the administrative district, regional or national level.

To provide an illustration on potential economic impacts future coffee production in 2050 has been estimated under assumptions of 50 percent and 75 percent reductions in production which we believe are realistic representations of the significant projected losses of suitable growing areas. Estimates have been made assuming:

(i) No overall yield improvements for those areas that remain in cultivation, and
(ii) Yield improvements for those areas that remain in cultivation resulting in 1.9% p.a. production growth to 2050 (based on crop projections for Sub Saharan Africa in Alexandratos & Bruinsma, 2012).

Figures A2.3 and A2.4 show results under these assumptions for total and regional production in 2050. The scale of potential differences in production between scenarios without climate change and with climate change scenarios is significant. When assuming no yield improvements (Figure A2.3) a 50 percent reduction in production due to climate change is estimated at about 19,500 tonnes (325,000x60 kg bags) per year ; and this figure rises to about 29,000 tonnes (488,000x60 kg bags) in the 75 percent reduction in production scenario.

[24] Note that there is a small difference between total production of coffee for 2012/3 from USDA (3,450,000 x 60 kg bags) and total export production from UCDA (3,582,629 x 60kg bags) but in this analysis we have assumed all coffee is exported.

With assumptions of yield improvements over time (Figure A2.4) a 50 percent reduction in national production due to climate change would amount to about 39,000 tonnes (650,000 p.a. x60 kg bags) and a 75 percent reduction in production to about 59,000 tonnes (978,000x60 kg bags) per year.

Figure A2.3: Arabica Coffee: Estimated Impacts of Climate Change on Production in 2050 without yield improvements (1000 x 60kg bags)

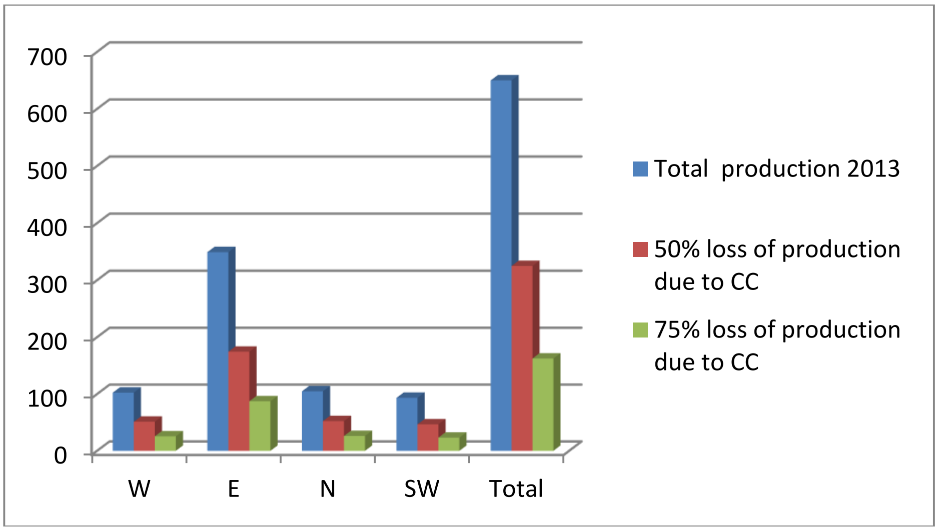
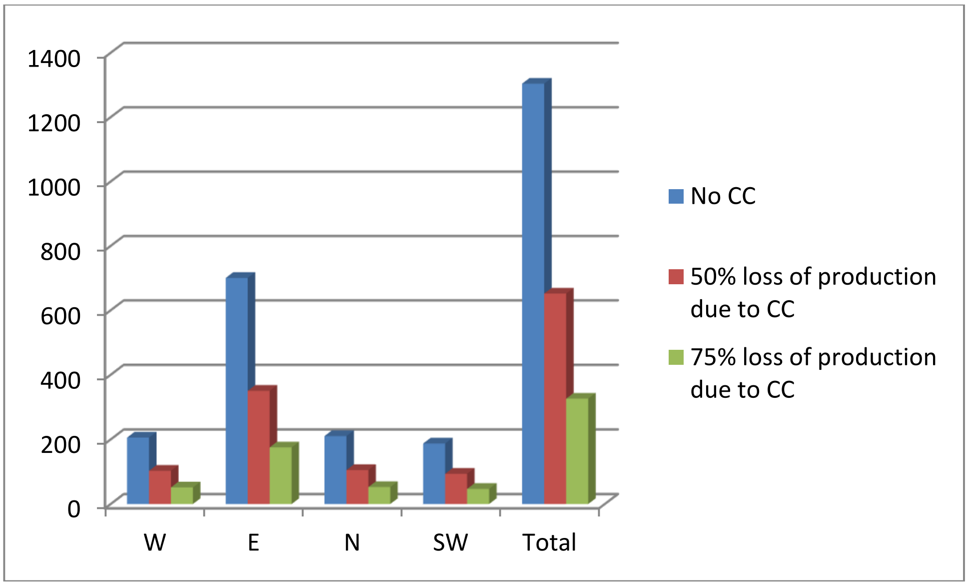


Figure A2.4: Arabica Coffee: Estimated Impacts of Climate Change on Production in 2050 with yield improvements (1000 x 60kg bags)



Estimates were also made for Robusta coffee production in 2050 using the same assumptions as above for Arabica (Figures A2.5 and A2.6). Since research on climate change impacts on Robusta coffee growing areas is much less developed than for Arabica these results should be treated with greater caution as they are simply illustrative of production impacts under the assumed scenarios.

Figure A2.5: Robusta Coffee: Estimated Impacts of Climate Change on Production in 2050 without yield improvements (1000 x 60kg bags)

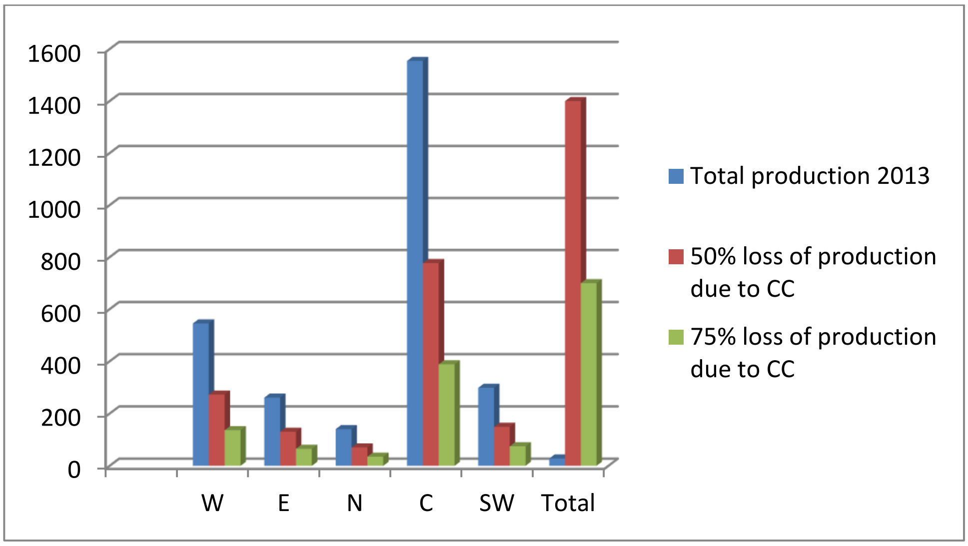
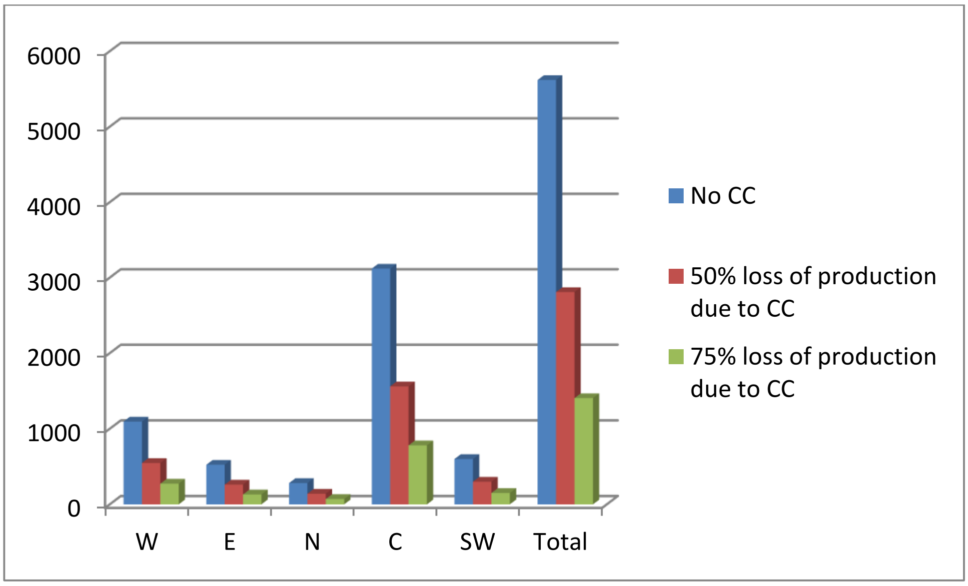


Figure A2.6: Robusta Coffee: Estimated Impacts of Climate Change on Production in 2050 with yield improvements (1000 x 60kg bags)



Impacts on Value of Coffee

The value of production in 2013 for each district and region of Uganda was estimated based on price data for Arabica and Robusta. Prices of coffee depend on quality, origin and certification with no single price. In the absence of detailed data on different prices paid in different districts and regions we calculated estimates of average prices for both Arabica (US$2.89 per kg) and Robusta (US$1.91 per kg) for 2013. This estimation was made based on the total value of Uganda exports of coffee for 2012/13 (US$432,694,059, source UCDA) and an assumption that Robusta was 0.66 of the price of Arabica[25]

[25] This was based on a calculation of the average price differential over the period 2008 to 2012 in the price data provided by Prof Bashaasha.

Using the coffee value estimates for 2013, estimates of the impacts of climate change on the value of coffee production in Uganda in 2050 were made under the assumptions of 50 percent and 75 percent reductions in production. A number of different estimates were made assuming:

(i) No overall yield improvements (for those areas that remain in cultivation) and no future price changes.
(ii) Yield improvements for those areas that remain in cultivation resulting in 1.9% p.a. production growth to 2050 (as explained in the production projections this is based on crop projections for Sub Saharan Africa in Alexandratos & Bruinsma, 2012) and no price changes.
(iii) Yield improvements as above, and coffee price increases of 1% p.a.
(iv) Yield improvements as above, and coffee price increases of 2% p.a.

It should be noted that the assumptions on improved yields in (ii) above (and Figures A2.8 A2.9 and A2.10) may prove to be quite conservative in that some literature sees the potential for substantially improved practices to increase yields significantly in Uganda. For example, the Sustainable Coffee Programme (SCP 2013) suggests potential for more sustainable farming practices to generate US$280 million in incremental coffee revenues.

Choice of price increases of 1% p.a. and 2% p.a. in (iii) and (iv) above are simply illustrative as we do not have available price projections to 2050. Coffee prices are known to be volatile and projections are usually in the short to medium term (World Bank projections go only up to 2025)[26] and the IFPRI crop modelling to 2050 used elsewhere in this report does not include future coffee prices. Long term forecasts for world market prices for crops under different climate change scenarios are too wide a range to be useable in this context[27].

Figures A2.7, A2.8, A2.9 and A2.10 show results for total and regional value of production in 2050 for Arabica coffee, under the above assumptions in comparison with values for 2013. These illustrate the scale of potential differences in value when comparing without climate change and with climate change scenarios. For example, in the scenario of yield improvements and price increase of 2% p.a (Figure A2.10) the total difference in value between no reduction in production and 50 percent reduction in production due to climate change is estimated at US$235 million in 2050; and this figure rises to about US$350 million in the 75 percent reduction in production scenario. Over half of this reduction in revenue would be experienced in the key Arabica growing areas in the Eastern region. Even without assumptions of price increases and yield improvements over time a 50 percent reduction in national production due to climate change would amount to about US$56m p.a. and a 75 percent reduction in production about US$88m p.a.

[26] See: http://knoema.com/WBCFPD2013Jan/world-bank-commodity-forecast-price-data

[27] See for example Fischer et al "The potential effects of climate change on world food production and security" (Table 9.10) http://www.fao.org/docrep/w5183e/w5183e0b.htm

Figure A2.7: Arabica Coffee: Estimated Impacts of Climate Change on Value of Production in 2050 without yield improvements or price changes (million US$)

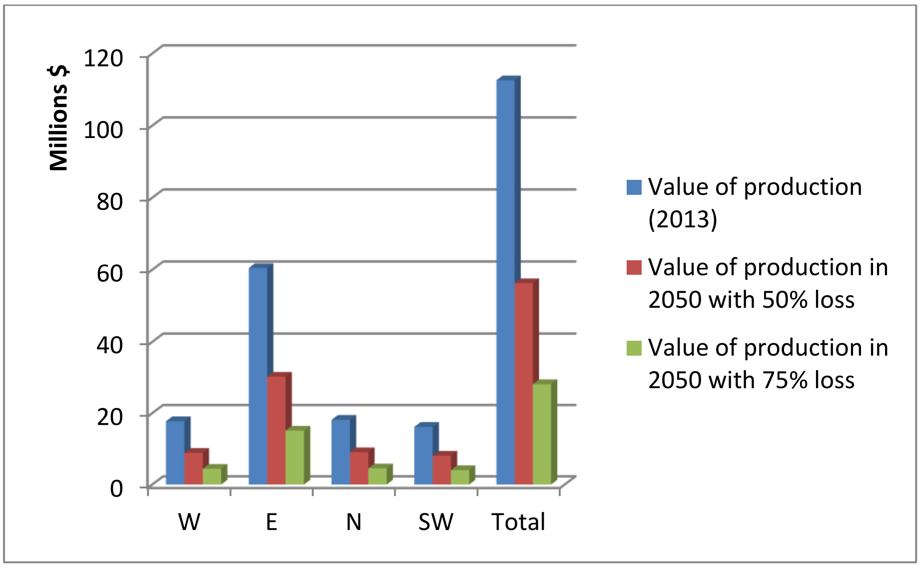


Figure A2.8: Arabica Coffee: Estimated Impacts of Climate Change on Value of Production in 2050 with yield improvements, no price changes (million US$)

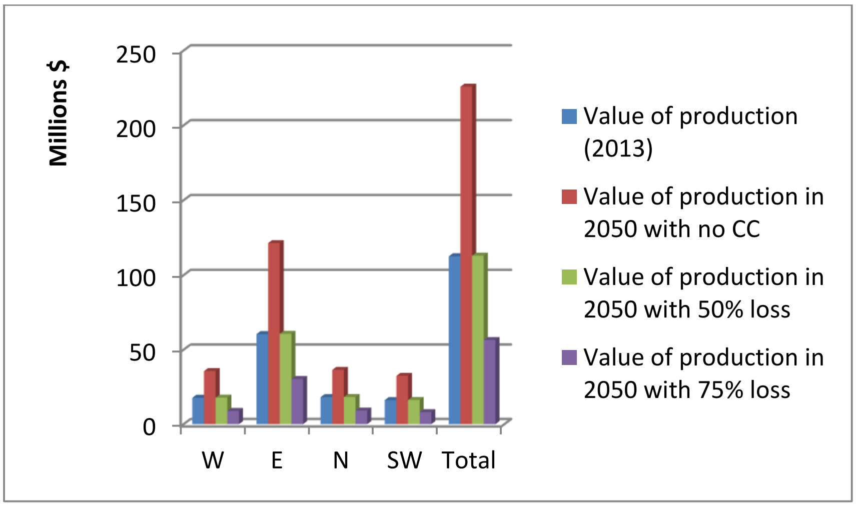


Figure A2.9: Arabica Coffee: Value of Production in 2050 with yield improvements and price increase of 1% p.a (million US$).

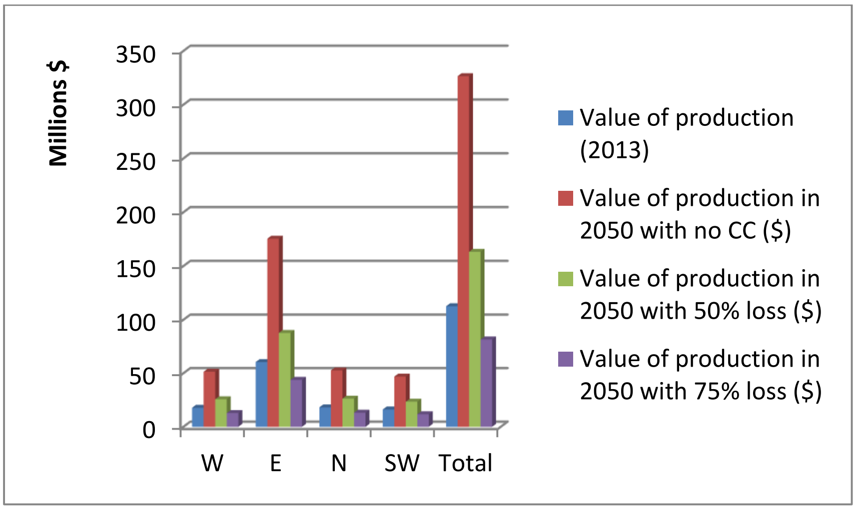
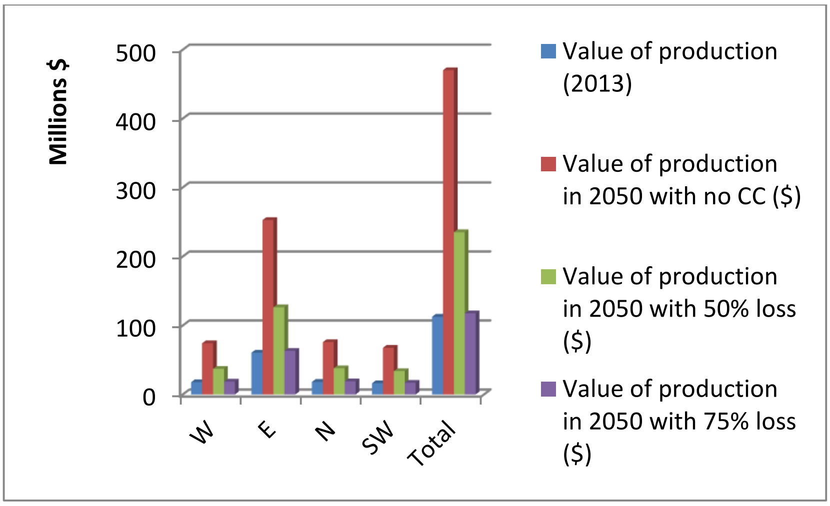


Figure A2.10: Arabica Coffee: Value of Production in 2050 with yield improvements and price increase of 2% p.a (million US$).



Estimates were also made for the value of Robusta coffee production in 2050 using the same assumptions as above for Arabica (Figures A2.11, A2.12, A2.13 and A2.14). As pointed out above these results are only illustrative of value impacts under assumed scenarios for loss of cultivation areas as there are no up to date projections on climate change impacts on Robusta coffee growing areas. In the scenario of yield improvements and price increases of 2% p.a (Figure A2.14) the total difference in value between no reduction in production and 50 percent reduction in production due to climate change is estimated as US$1,000 million in 2050; and this figure rises to about US$1500 million in the 75 percent reduction in production scenario.

Figure A2.11: Robusta Coffee: Estimated Impacts of Climate Change on Value of Production in 2050 without yield improvements or price changes (million US$)

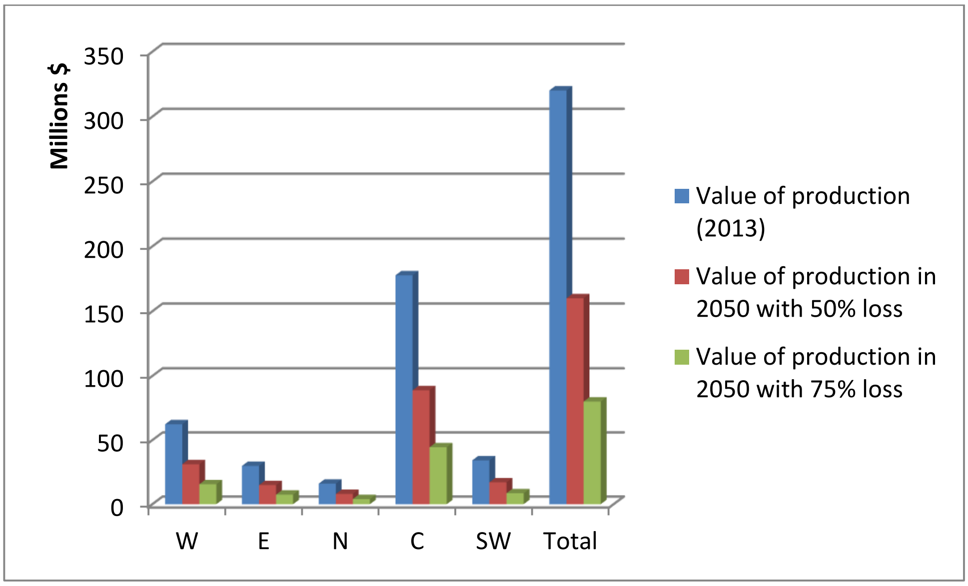


Figure A2.12: Robusta Coffee: Estimated Impacts of Climate Change on Value of Production in 2050 with yield improvements, no price changes (million US$)

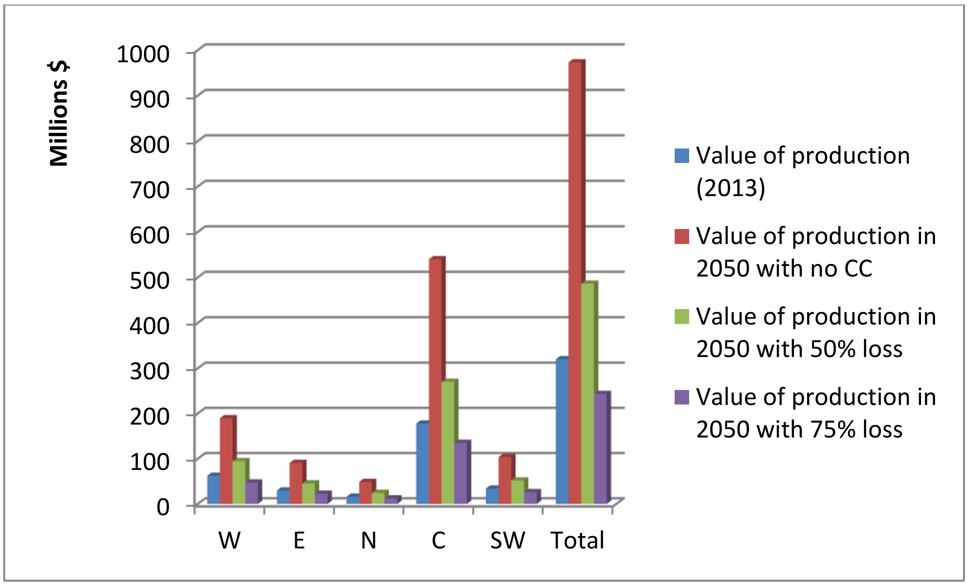


Figure A2.13: Robusta Coffee: Value of Production in 2050 with yield improvements and price increase of 1% p.a (million US$).

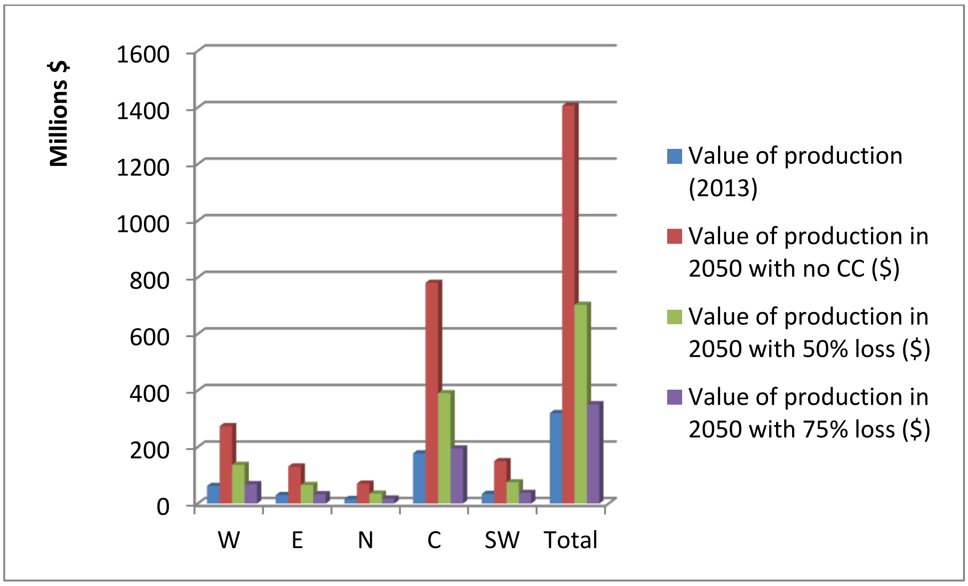
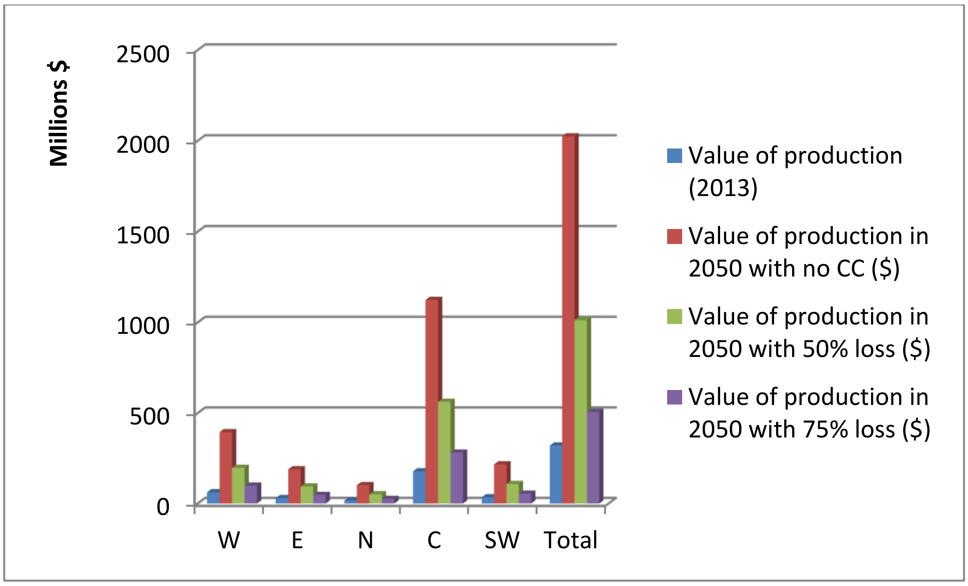


Figure A2.14: Robusta Coffee: Value of Production in 2050 with yield improvements and price increase of 2% p.a (million US$).



Tea Exports

Tea production in Uganda is an important export crop currently employing about 60,000 small scale farmers. In 2012 the total cultivation area was about 27,000 ha (FAOstat database) and export production was about 55,210 tonnes[28] which rose to 62,000 tonnes in 2013 with a trade value of about US$85m[29], over 3 percent of total export revenues for Uganda.

The key study on climate impacts by CIAT (2011), "Future Climate Scenarios for Uganda's Tea Growing Areas", concludes that as a result of projected changes in rainfall and temperature the area of suitability in the current tea growing areas in Uganda for will decrease quite substantially by 2050. The altitude for optimum tea growing is forecast to increase from between 1450 and 1650 metres currently to between 1550 and 1650 metres by 2050. However, the lack of land in these higher altitudes will mean that total land area available for tea cultivation will decrease. Figures A2.15, A2.16 and A2.17 indicate reducing areas of suitability for tea production from current to 2020 and 2050.

The results of the CIAT study indicate that districts becoming unsuitable for tea growing by 2050 include Kyejojo, Bundibugyo, Bushenyi, Kanungu and Masaka. The most significant loss of suitability (up to -60 percent) was forecast for Kabarole district. The study also analysed the potential for crop diversification in such areas and found that from the considered crops (maize, cassava, pineapple, banana, passion fruit and citrus) only banana would be somewhat suitable for growing in 2050. Some districts were predicted to remain suitable for tea but only with adaptation of agronomic management, such as Kabarole and Kisoro. Other areas were predicted to have increased suitability for tea growing, such as small areas around Rwenzori National Park and the corner of South Western Uganda. However, much of these are protected areas and therefore initiation of production of tea is a limited option and not recommended by the study.

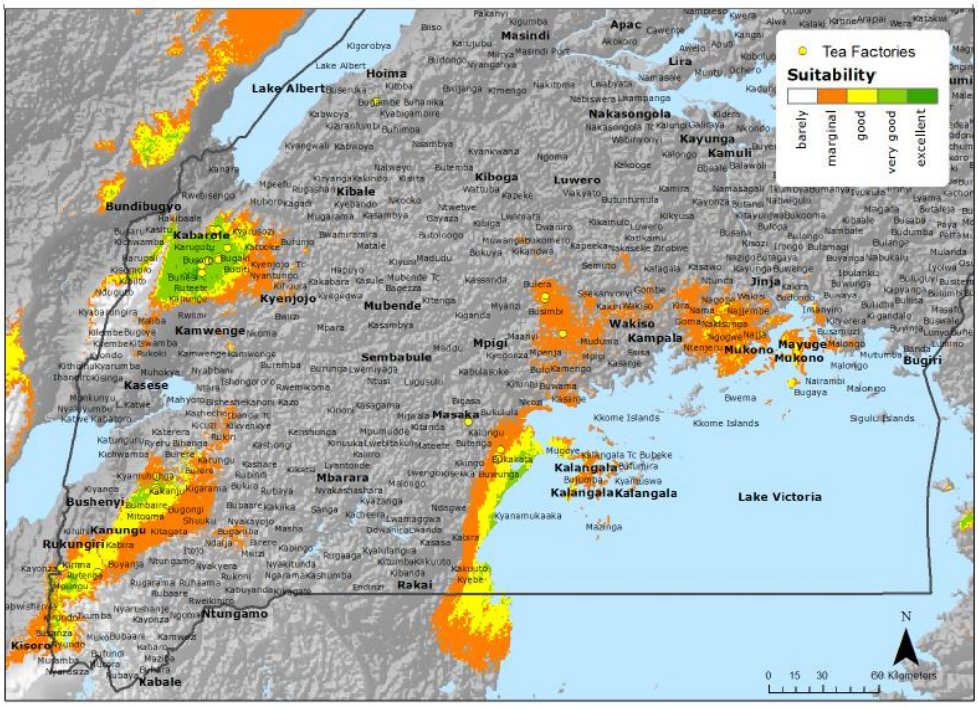
As in the case of coffee, the geographical representation of predicted changes in suitability for tea (only for SRES-A2 scenario) does not provide us with an appropriate dataset to make credible estimates of how these changes in areas of suitability will translate to changes in production potential at the administrative district, regional and national level. However, it is clear that the significant losses in growing area, without compensating increases in growing area available elsewhere in Uganda, will have significant impacts on the current value of tea exports These exports had a value of about US$74 million which rose to US$85 million in 2013[30].

[28] Source is UN Comtrade database. Exports given as 54,855 tonnes (2012) in Statistical Abstracts 2013. Uganda Bureau of Statistics (UBOS), Statistics House Kampala.

[29] UN Comtrade database: http://comtrade.un.org/data/

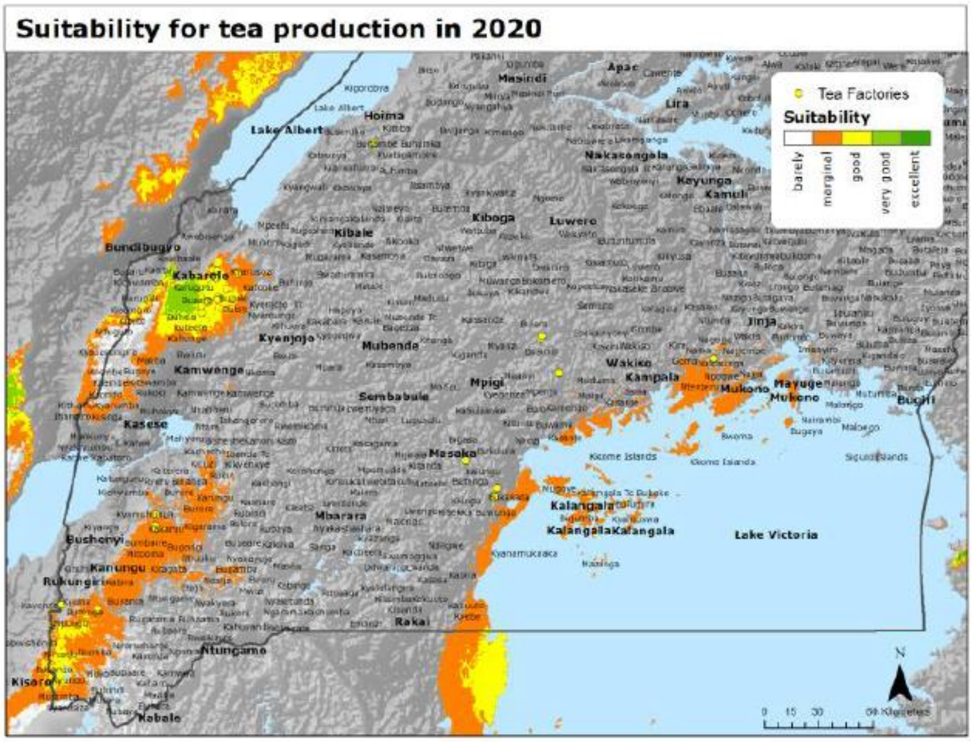
[30] UN Comtrade database: http://comtrade.un.org/data/

Figure A2.15: Current suitability of tea production areas



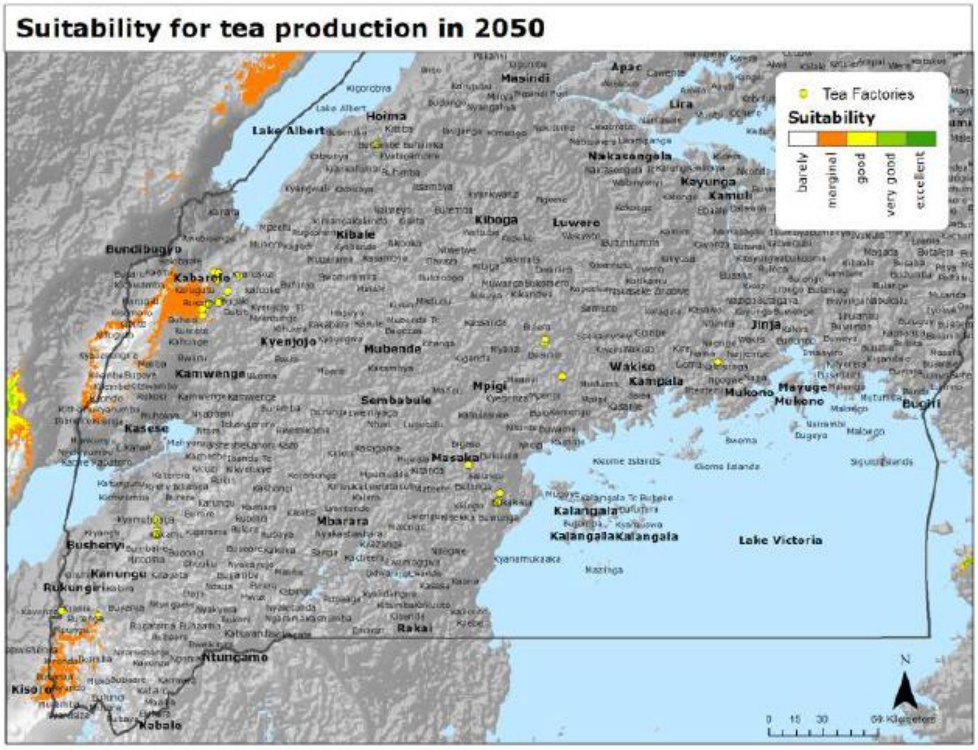
Source: CIAT (2011)

Figure A2.16: Future suitability of tea production areas (2020)



Source: CIAT (2011)

Figure A2.17: Future suitability of tea production areas (2050)



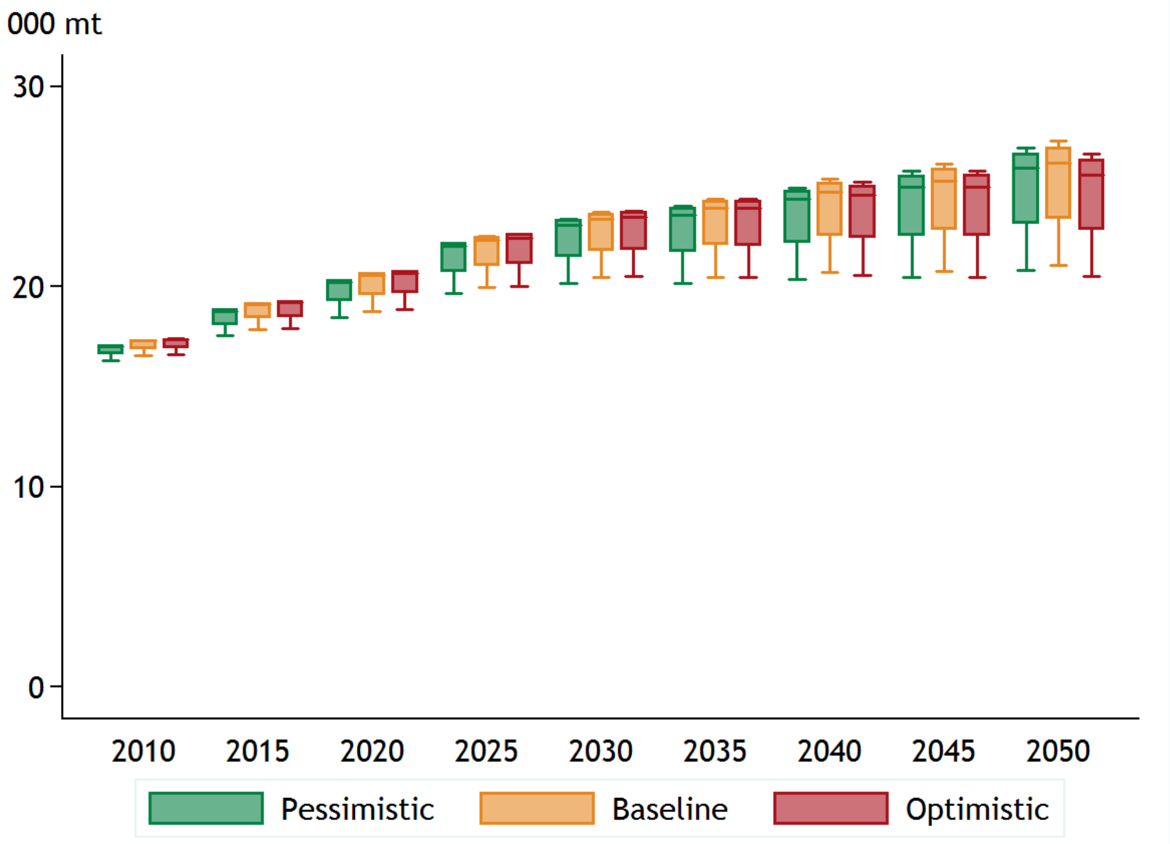
Source: CIAT (2011)

Cotton Exports

Cotton is among the top agricultural exports of Uganda with a trade value for in 2012 of US$77 million and in 2013 of US$33 million (Comtrade database). An estimated 250,000 households produce or earn their livelihood from cotton. Moreover, there is potential to increase cotton production with two thirds of arable land suitable for cotton cultivation according to industry sources (ITC, 2011a).

Existing global studies (see for example, ITC, 2011b) highlight potential impacts on cotton yields through increased atmospheric CO_2, changes in temperature, rainfall, soil moisture, and evapo-transpiration rates, and the levels of pests and diseases. However, our literature search did not find any dedicated studies on climate change impacts on cotton in Uganda. IFPRI climate change modelling data to 2050 does include cotton among the crops and results do not indicate a significant impact on cotton production in Uganda under the different climate and socio economic scenarios modelled. See Figure A2.18.

Figure A2.18: Impact on cotton production of climate changes for pessimistic, baseline and optimistic GDP/population scenarios in Uganda, 2010–2050



Source: IFPRI modelling 2014

Notes: The box and whiskers plot for each socioeconomic scenario shows the range of effects from the four future climate models used (see Section 3 for explanation of IFPRI methodology).

ANNEX 3: REVIEW OF STUDIES ON CLIMATE CHANGE IMPACTS ON AGRICULTURE RELEVANT TO UGANDA

This review summarises key issues in the economic assessment of agricultural vulnerability to climate change and reviews results of other studies of relevance to the Uganda assessment including those for other Sub Saharan Africa countries. It then comes to some conclusions on the availability and most promising sources of quantitative estimates of climate change impacts on agricultural products in Uganda.

The World Bank (2013) "Turn Down the Heat: Climate Extremes, Regional Impacts, and the Case for Resilience" report summaries the factors making agricultural productivity in Africa vulnerable to climate change as follows:

- High dependence on precipitation. As well as total rainfall, variability within seasons, years and decades may be a critical source of risk. In Sub-Saharan Africa the temporal distribution of rainfall can be a more significant factor than the total amount.
- Crop sensitivities to maximum temperatures during the growing season. For example, for maize each day in the growing season with temperature above 30°C reduces yields by one percent compared to optimal, drought-free rainfed conditions. Increases in temperature may cause non-linear changes in crop yields above high temperature thresholds.
- Varying responses to factors such as increasing CO_2 concentration (e.g. The fertilization effect of CO_2 may to some extent offset negative impacts on yield and production of climate change. This effect is stronger for C3 crops such as soybean and groundnut than for C4 crops, such as maize, millet, and sorghum[31].)
- Low adaptive capacities (such as the use of low-productivity technologies)

As a consequence, climate change can potentially affect agriculture by:

- Reducing the area suitable for agriculture,
- Altering the growing season length
- Reducing the yield potential
- Impacting production due to extreme events (drought, floods…). These impacts are as yet uncertain but expected to be significant.
- Increased incidence of plant diseases impacting agricultural productivity.

Shi & Tao (2014) note that previous studies have quantified the impacts of climate change on African agriculture at the regional or continental levels, mainly using three types of methods: crop process based models (e.g. Walker and Schulze 2008), statistical models (e.g. Schlenker and Lobell 2010) and econometric models (e.g., Seo et al. 2008).

The table in Annex 1 summarizes a number of key studies of climate change impacts on agricultural production in Uganda and in the wider region of Sub-Saharan Africa. Many of these studies focus on the impacts on crop

[31] C3 and C4 refer to the different pathways that plants use to capture carbon dioxide during photosynthesis..

yields resulting from climate change while there is much less coverage of other possible impacts noted above such as changes to cropping area, increased incidence and severity of extreme events (drought, floods) and incidence of plant diseases. Some of these studies such as Nelson et al (2010) and UNDP (2013) use these yield change estimates in their projections of economic impacts on prices and production, and in the assessment of consequences for livelihoods, poverty rates and malnutrition rates.

The following sections provide a discussion of key results of relevance to Uganda from the studies reviewed according to key types of impacts of climate change on agriculture as discussed above.

Crop Yield Impacts

It is important to note that estimates for changes in crop yield due to the impact of climate change can vary greatly due to a number of factors. These factors include (World Bank 2013):

- Geography. The relative significance of temperature and precipitation may vary according to agro-ecological zone. For example, Berg et al. (2012) find that yield changes in arid zones appear to be mainly driven by rainfall changes; in contrast, yield appears proportional to temperature in equatorial and temperate zones.
- Farm type, with small scale farmers often having much lower yields than large scale producers.
- Whether the areas is rainfed or irrigated.
- Response of different crops to changing climatic conditions.
- Different responses of cultivars of a given crop to changing climatic conditions. Cultivars are not specified in most of the studies and this may partly explain the broad range of projections.
- The coupling of climate and crop models, which are often based on different temporal and spatial scales and require downscaling of data.
- Level of adaptation assumed. Many studies do not explicitly take adaptation into account.

Table A3.1 below gives a summary of crop yield results relevant to Uganda from the literature review. Some yield results are available for the key crops produced in Uganda including maize, millet, sorghum, beans, rice and groundnuts. However, in most cases there is a large range in yield impact percentages given due to the factors outlined above and in many cases these are taken from generic estimates for the Sub Saharan and East Africa area. A more detailed summary of studies of climate change impacts on agricultural production in Sub-Saharan Africa is provided in Table A3.2.

In the case of **maize**, almost all the reviewed studies show a significant negative impact of climate change on yield to 2050 and beyond. Schlenker & Lobell (2010) give a mean decline for Uganda of 18%, although this does not take into account the fertilization effect or future adaptation measures and is at the high end of the range of study results. Nelson et al (2010b) project a decline of 4.6 to 0.8% (depending on climate model) for rainfed maize in Sub Saharan Africa as a whole. Shi & Tao (2014) have used historical data for 1961 to 2010 in Uganda to show a decline of 0 to 5% per 1°C mean temperature increase and a decline of 0 to 5% per 10% precipitation decrease. The most detailed work is given in Wasige (2009) which provides results for the 14 Agro-ecological zones in Uganda (See Figures 8 and 9 and Table 5 of the report) and in the IFPRI modelling reported in Bashaasha et al (2012) which maps projected yield changes due to climate change by district (see Figure 12.15 of the report). This demonstrates the local complexity of these yield estimates with a range of <-25% to >+25% according to area and some areas lost to production altogether.

Millet is also projected to have negative yield impacts from climate change to 2050. Berg, et al. (2012) give declines of 6 to 7% by mid century and 16 to 19% by 2100. The most detailed study is Wasige (2009) which has projections for millet yields for the 14 Agro-ecological zones in Uganda, most of which show declines.

Sorghum is an interesting case as the Wasige (2009) study concludes that under the climate scenarios used the yield will be higher for most areas of Uganda and therefore it could be seen as an adaptation crop. However, this conclusion differs from the range of yield declines of 0 to -10% for sorghum given in Schlenker & Lobell (2010).

Few of the reviewed studies gave yield data for the other key crops. The most useful data for **beans, rice and groundnuts** comes from Nelson et al (2010b) reporting on the modelling work for IFPRI although this is only reported here at the level of Sub Saharan Africa. This shows a range of yield impact results for each crop according to 2 climate models running with/without the fertilization effect.

Yield analysis for **cassava**, an important staple crop, is included in Bashaasha et al (2012) using IFPRI modelling results, with overall yield changes to 2050 given in Figure 12.20 under a number of scenarios. Information on cassava also comes from a Uganda local level case study (UNDP, 2013) which indicates limited yield impacts from climate change.

The studies of most interest are those that give estimates of climate impacts on yield by region/district or by agro ecological zone (AEZ) within Uganda. These are Bashaasha et al (2012), Wasige (2009) and the field study reported in (UNDP, 2013). The IFPRI modelling data reported in the Bashaasha study (and also used in global analysis in Nelson et al 2009, 2010a and 2010b) has been a key source for the analysis of food crops and livestock for Uganda discussed in Section 3 of this report.

Table A3.1: Summary of Yield Impact Results from Reviewed Studies per Crop

Crop	Study	Resolution	Yield Impact of CC	Period	Scenario	Note
Maize	Schlenker, & Lobell (2010)	Uganda	Mean impact: -18%	2050	A1B SRES	• 95 and 5 percentile also reported • Fertilization effect not included • Does not take into account future adaptation measures.
	Bashaasha et al (2012)	Uganda District Level	<-25% to >+25% according to district (see Figure 12.15). Some areas are lost to production.	2050	A1B SRES	• Range of values to estimated % yield change in districts of Uganda using 4 climate models. • Results based on IFPRI modelling.
	Shi & Tao (2014)	Uganda	• 0 to -5% per 1°C mean temp increase. • 0 to -5% per 10% P decrease.	1961 to 2010	Historical analysis	
	Knox et al (2012)	Uganda	Approx -14%	?	?	Part of meta-analysis but no detail given on this result for Uganda.
	UNDP (2013)	Uganda local level (3 case studies: 2 in Rakai, and 1 in Kapchorwa).	Impacts estimated to be "limited" in the 3 locations compared with predictions from studies conducted elsewhere in East Africa.	2030 and 2050		How representative of other parts of Uganda are these 3 locations?

	Wasige(2009)	14 Agro-ecological zones in Uganda	Results given by region/zone varying from: -20 % to -50 % - 10 % to - 20 %. < -10 % (See Figures 8 and 9 and Table 5)	2080-2100	Crop model simulation for 8 climate scenarios	Useful data on maize, sorghum and millet yield changes under rainfed, N-Fertilizer and Irrigation by AE Zone
	Nelson et al. (2010b)	Sub Saharan Africa	Irrigated: +0.3 to +0.8 Rainfed: -4.6 to -0.8	2050	A2 SRES	Range of Yield % change results are due to 2 climate models running with/without fertilization effect (Table 1)
Sorghum	Schlenker, & Lobell (2010)	Uganda	0 to -10%	2050	A1B SRES	See above note for Maize
	Wasige(2009)	14 Agro-ecological zones in Uganda	Results given by zone and climate scenario (See Figures 15). Report concludes that under climate scenarios yield will be higher for most areas of Uganda.	2080-2100	Crop model simulation for 8 climate scenarios	Useful data on maize, sorghum and millet yield changes under rainfed, N-Fertilizer and Irrigation by AE Zone
Millet	Schlenker, & Lobell (2010)	Uganda	0 to -10%	2050	A1B SRES	See above note for Maize
	Wasige(2009)	14 Agro-ecological zones in Uganda	Results given by zone and climate scenario show mostly declines in yield. (See Figures 14)	2080-2100	Crop model simulation for 8 climate scenarios	Useful data on maize, sorghum and millet yield changes under rainfed, N-Fertilizer and Irrigation by AE Zone

	Berg, et al. (2012)	Equatorial fully humid climate zone (which includes most parts of East Africa)	• -16 to - 19% percent for 2100. • -6 to -7% for mid century (2050?)	2100 and 2050	A1B SRES and A2 SRES	
Groundnuts	Nelson et al. (2010b)	Sub Saharan Africa	Irrigated: -11.5 to 4.2 Rainfed: -8.6 to +14.2	2050	A2 SRES	Range of Yield % change results are due to 2 climate models running with/without fertilization effect (Table 1)
	Hertel, Burke & Lobell (2010)	East Africa	Low -15%, Med -3% High 9%	2030	Low, medium and high scenarios defined in study	Generic data and not clear which study the yield figures come from.
Rice	Nelson et al. (2010b)	Sub Saharan Africa	Irrigated: -14.1 to +5.7 Rainfed: -0.5 to +8.1	2050	A2 SRES	Range of yield change results are due to 2 climate models running with/without fertilization effect (Table 1)
	Hertel, Burke & Lobell (2010)	East Africa	Low -15%, Med -3% High 9%	2030		Generic data and not clear which study the yield figures come from.
Wheat	Nelson et al. (2010b)	Sub Saharan Africa	Irrigated: +0.7 to +9.7 Rainfed: -21.9 to -11.2	2050	A2 SRES	Range of yield change results are due to 2 climate models running with/without fertilization effect (Table 1)
	Hertel, Burke & Lobell (2010)	East Africa	Low -15%, Med -3%	2030		Generic data and not clear which study the yield figures come from.

			High 9%			
Cassava	Bashaasha et al (2012)	Uganda District Level ?	Estimated overall change in yields under a number of scenarios shown in Figure 12.20.	2050	A1B SRES	• Changes in yields per district are not reported (unlike for maize in the same study) • Results based on IFPRI modelling.
	UNDP (2013)	Uganda local level (3 case studies: 2 in Rakai, and 1 in Kapchorwa).	Estimates impact will be limited in the 3 locations compared with predictions from studies conducted elsewhere in East Africa.	2030 and 2050		How representative of other parts of Uganda are these 3 locations?
Bean	Nelson et al. (2010b)	Sub Saharan Africa	Irrigated: + 4.6 to +17.8 Rainfed: -3.5 to +19.1	2050	A2 SRES	Range of yield change results are due to 2 climate models running with/without fertilization effect (Table 1)
Soybean	Hertel, Burke & Lobell (2010)	East Africa	Low -15%, Med -3% High 9%	2030		Generic data and not clear which study the yield figures come from.

NB: Yield figures refer to rainfed crops unless stated for irrigation. Currently much of the irrigation in Uganda is for rice.

Studies on Climate Change Impacts on Livestock.

Much less research has been published on the effects of climate change on livestock than on crops. Moreover , there are apparent inconsistencies in the findings of studies reviewed in the World Bank (2013) paper with respect to how changes in precipitation is projected to affect livestock yield and the relative vulnerability of large and small farms.

Specific factors that are expected to affect livestock include the following (World Bank 2013):

- The quantity and quality of feeds
- Heat stress altering feed intake, mortality, growth, reproduction, maintenance, and production.
- Livestock diseases due to change to diseases themselves and the spread of disease through flooding.
- Water availability, especially since water consumption increases with warmer weather.
- Biodiversity: the livestock sector is a significant driver of habitat and landscape change and can cause biodiversity loss.

The study by Seo et al (2008) examined the distribution of climate change impacts across the 16 agro-ecological zones in Africa. It included 11 countries including 9 nine Sub-Saharan African countries but did not include Uganda. The results suggested that warming is likely to increase livestock income unless there are large increases in temperature along with substantial drying.

It therefore concludes that reductions in crop income can be partially offset by increases in livestock income and that adaptation to future changes in climate by farmers can not only include adjusting methods of growing crops but also switching between crops and livestock production.

Seo and Mendelsohn (2007) analyzed the impact of climate change on animal husbandry in Africa by looking at the differences between large and small farms. While large farms produce livestock primarily for sale, small farms use livestock for animal power, food supply, and to a lesser extent for sale. The study found that higher temperatures reduce both the size of the stock and the net value of stock for large farms but not for small farms. It is suggested that the higher vulnerability of larger farms may be due to their reliance on breeds, such as beef cattle, that are less suited to extreme temperatures, while smaller farms tend to be able to substitute with species, such as goats, that can tolerate higher temperatures. The discrepancy in the vulnerability of large and small farms observed with temperature increase is not as marked when it comes to precipitation impacts; here, both large and small farms are considered vulnerable.

Other Climate Change Impacts on Agricultural Production

Climate change impacts on agricultural production other than on yield potential are less well reported in the reviewed studies. Changes in the area suitable for agriculture are covered to some extent in the IFPRI modelling of production changes. In fact, Uganda is given as among countries with more than 1 million ha of crop area increase 2010–2050 (Figure 2.12 in Nelson et al, 2010a).

There is also limited detailed quantitative analysis on the impact on production of extreme events (drought and floods) even though these impacts are already known to be significant in Uganda. Shi & Tao (2014) note that Uganda is in the highest range of countries for drought impacts. Their study of data since 1960 used the standardized precipitation evapotranspiration index (SPEI) as representative of drought conditions. A decrease by 0.5 SPEI was shown to result in 30% losses of maize yields including for Uganda which was one of the countries where SPEI variability led to greater instability of maize yields. Brown et al. (2011) find a significant and negative correlation between drought and GDP growth per capita: a 1-percent increase in the area of a

Sub-Saharan African country experiencing moderate drought correlates with a 2–4 percent decrease in GDP growth (World Bank 2013).

There is also limited quantitative analysis found on the potential for increased incidence of plant diseases from climate change to impact agricultural productivity.

Studies on Livelihood and Poverty Consequences of Climate Change Impacts on Agriculture

A number of studies such as Nelson et al (2010) and UNDP (2013) have also analyzed and made projections of economic impacts of climate change on macroeconomic variables in agriculture (prices, production, trade) and made assessments of consequences for livelihoods, poverty rates and malnutrition rates.

Other key studies addressing these issues are as follows:

- **The poverty implications of climate-induced crop yield changes by 2030. Global Environmental Change (**Hertel, Burke & Lobell, 2010). Show that, by 2030, poverty implications because of food price rises in response to productivity shocks have the strongest adverse effects on non-agricultural, self-employed households and urban households, with poverty increases by up to one third in Malawi, Uganda, and Zambia.
- **Assessing Climate Change Impacts And Adaptation Strategies For Smallholder Agricultural Systems In Uganda** (Bagamba, et al, 2012) In this paper, using the trade off analysis model, the impact of climate change on peoples' livelihoods and possible adaptation strategies to increase the resilience and sustainability of agricultural systems in three regions of Uganda (central, Masaka and southwest) are analysed. The results show that 70-97% of households will be adversely affected by climate change in Uganda. The southwest will be most affected due to smaller farm sizes and limited livelihood alternatives. There will be no positive gains from encroaching on swamps, which is one of the reported adaptation strategies to climate related stresses. Improving productivity of important crops (bananas for southwest, and sweet potatoes and bananas for central region), in addition to adoption of grade cattle will likely be a better adaptation strategy for climate change.
- **Uganda Climate Change Vulnerability Assessment Report.** (USAID, 2013). The study provides a great deal of information on the selected crops and the vulnerability of households according to different characteristics and their adaptive capacity according to different districts and household types in the survey. However, this is a statistical analysis of vulnerability to climate change based on the survey rather than a monetised economic analysis of loss of assets. As such it is useful in informing how the results of the economic assessment can be interpreted in terms of impacts on vulnerable groups and districts.

Table A3.2: Summary of studies of climate change impacts on agricultural production in Sub-Saharan Africa/Uganda

Study	Method	Products	Key results	Caveats/comments
Schlenker & Lobell (2010) Robust negative impacts of climate change on African agriculture.	Estimated country-level yields for the 2050s by using future temperature and precipitation changes from 16 GCMs for the A1B SRES scenario and applying these to two historical weather data series (1961 to 2000 and 2002, respectively) with regression analysis.	Maize, Sorghum, millet, Groundnuts, Cassava	• Mean percentage, 95 percentile and 5 percentile yield changes per crop across Sub-Saharan Africa and per country. • For **Uganda** mean changes are: 2 maize -18% (Figure 5 in source study), 3 sorghum, millet, groundnut 0 to -10% (Figure 6 in source study).	• Fertilization effect not included although maize, sorghum, and millet are C4 crops with a lower sensitivity. • Does not take into account future developments in technology or shifts in the growing season as adaptation measures.
Shi & Tao (2014) Vulnerability of African maize yield to climate change and variability during 1961–2010	Databases of maize yields and climate variables (including temperature, precipitation and SPEI) were used to analyze the vulnerability of maize yields to climate change and variability for each country in Africa (1961 and 2010)	Maize	Results for **Uganda**: • In the middle range of countries for T impacts. 1°C Tmean increase decreased yields 0 to 5%. • High yield instability, i.e. a small variance of Tmean can result in a large variance of yields • In the second highest range of countries for P impacts. Decrease of 10%Pave resulted in 0 to 5% decrease of maize yields. • In the highest range of countries for drought impacts. Decrease by 0.5 SPEI resulted in 30% losses of maize yields. • Uganda was one of the countries where SPEI variability led to greater instability of maize yields.	• The study found that countries with higher trends in maize yields or better management conditions also had higher yield fluctuations. • Crop yield datasets are at country level and within-country heterogeneities have not been considered. • Impacts of extreme climate conditions, which may become more frequent in parts of Africa, were not quantified.
Berg, et al. (2012). Projections of	Assessed potential impacts on crop productivity for a	Millet	• Across both regions and for all climatic zones considered,	• Finds that potential fertilisation effect

climate change impacts on potential C4 crop productivity over tropical regions.	C4 millet cultivar, in a tropical domain, including Africa and India, for the middle (2020–49) and end of the century (2070–99), compared to the 1970–99 baseline.		overall decline in productivity of millet was –6 percent (with a range of –29 to +11 percent) for the highest levels of warming by the 2080s. • Long-term decline in yield of 16–19 percent is projected for the equatorial fully humid climate zone (which includes most parts of East Africa) under SRESA1B and SRESA2 scenarios respectively, for 2100. • Projected changes for the mid-century are around 7 percent under the A1B and 6 percent under the A2 scenario for the equatorial fully humid zone.	for the A2 scenario is limited. • Yield declines results are likely to be optimistic as based on assumptions of optimal crop management that are not often achieved in practice.
Knox et al (2012) Climate change impacts on crop productivity in Africa and South Asia	Assessed the projected impacts of climate change on the yield of eight major crops in Africa and South Asia using a systematic review and meta-analysis of data in 52 original publications.	Rice, Wheat, Maize, Sorghum, Millet, Cassava, Yam Sugarcane	• Mean yield reduction of 8% was identified for Africa, with significant mean reductions projected for Wheat (17%) Maize (5%), Sorghum (15%), and Millet (10%). *Period?* • Projected mean yield change for rice is not significantly different from zero. • Little detail for **Uganda** or other East African countries except for Maize (Approx 14% reduction but unclear which study this was referring to and time period?)	• Conclusion on yield reductions too general to use for Uganda except when no other data available. • Study ignored impact of any climate related shocks such as floods, droughts and pest attacks. • For most crops and regions, there were too few studies or no consistent message regarding changes in yield impact over time.
Hertel, Burke & Lobell 2010 "The poverty implications of	In the analysis of how changes in agricultural productivity from climate change will	Rice, wheat, coarse grains, oilseeds,	Productivity to 2030 for low, medium and high scenarios: Rice: -15, -3 , 9	• Generic data used. Not clear which study the Uganda production figures come from but

climate-induced crop yield changes by 2030. Global Environmental Change”	affect poverty (see Table 2) production changes per crop to 2030 for Uganda are used from literature review.	cotton, and other crops.	Wheat: -15,-3, 9 Course grains: -22, -10, 2 Oilseeds: -15, -3 , 9 Sugar: 0 ,0 ,0 Cotton: -15, -3 , 9 Other crops: -15, -3 , 9	same as other East African countries. • No adaptation assumed? 4
Bashaasha et al (2012) Uganda chapter in *East African Agriculture and Climate Change: A Comprehensive Analysis*	Comparing future yield results to current or baseline yield results, both from the DSSAT software, produced results for rainfed maize mapped by region of Uganda. Simulation results from IMPACT produced graphs for production, yield, area harvested, net exports, and world price under 3 future GDP and population scenarios. Based on global analysis conducted for IFPRI reported in Nelson et al (2010a)	Maize and Cassava	• Maps estimated % yield change in area of Uganda using 4 climate models for rainfed maize, 2000–2050, A1B scenario (see Figure 12.15). • Graphs for production, yield, area harvested, net exports, and world price under 3 future GDP and population scenarios. Each of these figures shows the range of values from the four future climate scenarios for each GDP/Population scenario. (Figures 12.19 and 12.20) • CNRM-CM3 GCM predicts severe losses in the east, some areas exceeding 25% and some lost for maize altogether. • Estimates impact of 3 future GDP and population scenarios on number, % and Kilocalories per capita of malnourished children (Figure 12.16, 12.17, 12.18) in Uganda to 2050 under four future climate scenarios.	• Results show overall yields of maize tripling by 2050 and yields of Cassava increasing by about 80 percent. 5
UNDP (2013) *Climate Risk Management for Sustainable*	As part of the UNDP project McCandless et al. (2012) studied the impacts of climate	Bean Maize	• Figures 15 and 16 show the average bean and maize yields for the years 2010, 2030 and 2050	• The paper on these estimates McCandless et al. (2012) is listed as

Crop Production in Uganda: Rakai and Kapchorwa Districts	change on maize and bean yields in Katatenga and Kayonza villages in Rakai, and in Sanzara parish in Kapchorwa. They used an ecophysiological crop model (DSSAT) to estimate how predicted changes in temperature and precipitation will influence crop growth and yield.		with three different treatments (no inputs, perfect irrigation and perfect nitrogen fertilization). • Estimates that impact of climate change on maize and bean production will be limited in the three locations and for both crop seasons, as compared with predictions from studies conducted elsewhere in East Africa. • In the three sites, climate change impacts can be almost completely offset through investment in water management (irrigation), especially on bean production and, to a much lesser extent, through investment in fertilization. The model predicts irrigation investments will increase maize and bean production in Rakai and bean production in Kapchorwa well beyond the current output by 2050, notwithstanding climate change. 6	unpublished document. • Potentially key conclusions but how representative of other parts of Uganda are these 3 locations? • Climate impacts may be underestimated because DSSAT does not account for the impacts of extreme events, pests and diseases, as well as other impacts (such as deforestation). • The model was limited by a lack of available historical daily climate records for Rakai and Kapchorwa
Wasige, J. E. (2009). *Assessment of the Impact of Climate Change and Climate Variability on Crop Production in Uganda*.	Study was designed to: 1) evaluate the impact of climate variability and change on Crop production, 2) explore potential impact at agro-ecological scale, and 3) adapt crop	Maize Sorghum Millet	Under projected climate change to 2080-2100: • Crop yield will decline by 10 % to 50%. • There will be poor response to fertilizer applications by 23 % to 37 %. Irrigation	• Useful data on maize, sorghum and millet yield changes under rainfed, N-Fertilizer and Irrigation by 14 Agro-ecological zones in Uganda (see Figures 6 to 15)

	production practices to counter the impacts. Site-based simulations were developed to analyze alternative agricultural management systems, including changes in crop variety, fertilizers responses and alternative crops. DSSAT model outputs were joined to the polygon attribute table and results displayed in thematic digital maps/GIS.		may boost grain yields by 35 to 73 %. • Possible adaptation strategies may mean adopting irrigation or switching to more water efficient crops such as sorghum or millet.	• Longer timeframe to 2100 than other studies 7
Bagamba et. al. (2012). *Assessing Climate Change Impacts and Adaptation Strategies for smallholder agricultural systems in Uganda*	Tradeoff Analysis model for Multi-Dimensional impact assessment (TOAMD) used to analyze the impact of climate change on livelihoods and possible adaptation strategies in three regions of Uganda (central, Masaka and southwest).	Sweet potatoes, Bananas, Maize, Beans and Cassava Livestock products	• Figures 2 and 3 show % of farms losing and gaining under different yield assumptions with no adaptation. • Figures 4 and 5 show farms losing and gaining under different yield assumptions with adaptation of (i) encroaching on swamps, (ii), adoption of grade cattle, and (iii) livestock crop integration.	To analyse the effects of climate change on livelihoods they did not use estimates of changes in crop and livestock yields and as "such type of data are rarely available" but assumed yield declines by 10 to 40%. Hence this is a scenario analysis not based on actual estimates of yield changes.
Challinor et al (2007) *Assessing the vulnerability of food crop systems in Africa to climate change*	Discusses three aspects of the vulnerability of food crop systems to climate change in Africa: the assessment of the sensitivity of crops to variability in climate, the adaptive capacity of farmers, and the role of institutions in adapting to climate change.	Maize Millet Cereals	• Table 1 gives a selection of studies of the impact of climate change on crop yield in Africa. • All show a wide range of % change in yield but most scenarios are negative change.	Useful general discussion of issues in Africa but crop yield data all over 10 years old.

Di Falco et al (2011). Does Adaptation to Climate Change Provide Food Security? A Micro-Perspective from Ethiopia.	Focus on driving forces behind farm households' decisions to adapt to climate change, and the impact of adaptation on farm households' food productivity. Estimates a simultaneous equations model with endogenous switching to account for the heterogeneity in the decision to adapt or not, and for unobservable characteristics of farmers and their farm.	Teff, maize, wheat, barley, beans	• Access to credit, extension and information are found to be the main drivers behind adaptation. Adaptation *increases* food productivity, • Farm households that did not adapt would benefit the most from adaptation. • Results show increases in average expected production per ha in adaptation and no adaptation scenarios (Table 4).	Useful in illustrating possible yield benefits of adaptation options.
Calzadilla, A., Zhu, T. Rehdanz, K., Tol, R.S.J. and Ringler, C. (2009). Economy-wide impacts of climate change on agriculture in sub-Saharan Africa	Two possible adaptation scenarios to climate change for Sub-Saharan Africa are analyzed under the SRES B2 scenario. The first scenario doubles the irrigated area in Sub-Saharan Africa by 2050, compared to the baseline, but keeps total crop area constant. The second scenario increases both rainfed and irrigated crop yields by 25% for all Sub-Saharan African countries. The two adaptation scenarios are analyzed with IMPACT, a partial equilibrium agricultural sector model combined with a water simulation module,	Rice Wheat Other cereal grains Vegetables, fruit , nut Oilseeds Sugarcane, sugar beet	The efficacy of the two scenarios as adaptation measures to cope with climate change is discussed. Due to the limited initial irrigated area in the region, an increase in agricultural productivity achieves better outcomes than an expansion of irrigated area. Even though Sub-Saharan Africa is not a key contributor to global food production (rainfed, irrigated or total), both scenarios help lower world food prices, stimulating national and international food markets. Table 4 presents average yields for SS Africa by crop type for the 2050 (SRES B2) baseline simulation. Displayed are average levels for 7 crop types as well as	Table 4 gives good yield estimates for 2050 for comparison with other studies

	and with GTAP-W, a general equilibrium model including water resources. irrigated or total), both scenarios help lower world food prices, stimulating national and international food markets.		minimum and maximum levels for rainfed and irrigated harvested area according to the 16 GTAP-W regions including	
Seo et al (2008) Ricardian Analysis of the Distribution of Climate Change Impacts on Agriculture across Agro-Ecological Zones in Africa.	Examines distribution of climate change impacts across the 16 agro-ecological zones in Africa using data from FAO combined with economic survey data GEF/World Bank project. Net revenue per ha of cropland is regressed on a set of climate, soil, and socio-economic variables using different econometric specifications "with" and "without" country fixed effects.	Includes crop sector and livestock sector income for each farm	• The agro-ecological zone classification can help explain the variation of impacts. • Table 5a and 5b show Climate Change Impacts by AEZs (change in USD per ha for two climate models for 2020, 2060 and 2100) with and without Country Fixed Effects. • Currently productive areas such as dry/moist savannah are more vulnerable to climate change while currently less productive agricultural zones such as humid forest or sub-humid zones become more productive in the future.	• Studies gives an illustration of potential magnitude of climate effects on revenue per AEZ which can be matched to AEZs of Uganda. • See related study Kurukulasuriy, P. & Mendelsohn, R.(2008) which used this method and data to estimate change in Annual Crop Revenue by Country. For Uganda calculates a loss of 0.4 and 1.3 USD bn/year under the 2 climate models used (PCM and CCC).
Muller et al (2011) Climate change risks for African agriculture	Review of climate change impact assessments for African agriculture and food security (14 quantitative, 6 qualitative).	General	Figure. 1 shows the range of reported impacts on African agriculture per spatial domain illustrating the vast range of possible impacts. Overall, agricultural production in many African countries will be severely compromised, with high confidence.	Results given in Figure 1 are too general and not crop specific enough for purposes of Uganda study but useful for providing context and caveats for results.

			However, as there are so many climatic and non climatic aspects that determine agricultural productivity that are mainly not considered in the reviewed studies, there is only low confidence in what the extent of impact of climate change on African agriculture will be.	
Nelson et al (2009) Climate Change Impact on Agriculture and Costs of Adaptation	Uses a global agricultural supply-and-demand projection model (IMPACT) linked to a biophysical crop model (DSSAT) of the impact of climate change based on simulations of A2 scenarios in two climate models (NCAR and CSIRO). Provides detailed estimates of the impacts of climate change on agricultural production, consumption, prices, and trade, and estimates costs of adaptation.	Rice, wheat, maize, soybeans, and groundnuts	• Table 1 gives results for Climate-change induced yield effects by crop and management system to 2050. These are reported by (i) by climate model (ii) rainfed/irrigated and (iii) with and without fertilisation effect. However, data only reported at Sub Saharan Africa level. • Also reports estimates for world crop prices, crop production, per capita consumption and total malnourished children to 2050. • Additional annual investment needed to counteract the effects of climate change on nutrition.	• Part of IFPRI programme of research. • Yield change data given are general but results for economic impacts are important to take into account in Uganda study. • NCAR scenario has higher precipitation in Sub-Saharan Africa than does CSIRO.
Nelson et al. (2010b). The Costs of Agricultural Adaptation to Climate Change	The biophysical modelling combines crop modelling results from DSSAT) and the SPAM data set of crop location and management techniques. The results are fed	Rice, wheat, maize, soybeans, and groundnuts	• Yield % change results for Sub Saharan Africa to 2050 under 2 climate models and with/without fertilization effect (Table 1): Maize (irrigated): +0.3 to +0.8 Maize (rainfed):-4.6 to -0.8	World Bank paper linked to Nelson et al. 2010a and 2009.

	into IFPRI's global agricultural supply and demand projection model, IMPACT.		Rice (irrigated): -14.1 to +5.7 Rice (rainfed): -0.5 to +8.1 Soybean (irrigated): + 4.6 to +17.8 Soybean (rainfed): -3.5 to +19.1 Wheat (irrigated):+0.7 to +9.7 Wheat (rainfed): -21.9 to -11.2 Groundnut (irrigated):-11.5 to 4.2 Groundnut (rainfed): -8.6 to +14.2 • See also Table 6. Combined biophysical and economic yield effects including millet and sorghum and Table 7 crop production effects, accounting for both the changes in yield shown and changes in crop area.	
Nelson et al (2010a) Food Security, Farming, and Climate Change to 2050: Scenarios, Results, Policy Options	As for Nelson 2010b and 2009	Maize, rice, and wheat	• Figures 1.9 to 1.14 show global maps of yield effects of the A1B climate scenario with the CSIRO and MIROC GCMs on rainfed maize and wheat and irrigated rice. • Overall yield outcomes for maize, rice, and wheat are given in Table 4.1. • Estimates of crop area losses are also reported. Uganda given as among countries with more than 1 million ha of crop area increase 2010–2050 (Figure 2.12)	From Figures 1.9 to 1.14 detail for Uganda is unclear. Thus access to data underlying maps would be very useful (especially for more detailed maps for Uganda in Bashaasha et al) Is data on production changes to 2050 (combining yield and area changes) available for Uganda?

			• Yield and area changes are combined to give production changes to 2050 for maize, rice, and wheat (Table 2.5) but this is only at "level of low income developing countries"	
Hertel, Burke & Lobell 2010 "The poverty implications of climate-induced crop yield changes by 2030. Global Environmental Change"	Disaggregated data on household economic activity for 15 countries used with GTAP model to analyse how changes in agricultural productivity from climate change will affect poverty via agricultural incomes and food prices.	• Crops included: rice, wheat, coarse grains, oilseeds, cotton, and other crops.	Predicts changes in poverty headcount by household group by 2030 under 3 productivity outcomes. • In low productivity scenario, prices for major staples rise 10-60% by 2030. • Yield changes are poor predictors of changes in national poverty because earnings changes can be more important driver of household poverty than commodity price changes. • Food price rises due to productivity shocks have strongest adverse effects on non-agricultural, self-employed households and urban households, with poverty increases by up to one third in Malawi, Uganda, and Zambia. Results for **Uganda**: • Total welfare change (% of agricultural value-added) = approx +20% (low productivity scenario), +5% (med scenario), +2 (high scenario)	• Generic regional data used for productivity shocks in Uganda. • No adaptations assumed. 11

	9 (See Figure 3 of the study) • Shows one of highest % declines in poverty headcount in low Productivity scenario. Especially accounted for by "rural diversified" group. 10 (See Figure 5 of the study)	