Project Document

An assessment of the economic and social impacts of climate change on the agriculture sector in the Caribbean

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Executive summary

The main objective of the present study was to determine the value of impacts due to climate change on the agricultural sector in the Caribbean under the Intergovernmental Panel on Climate Change Special Report on Emissions Scenarios A2 and B2 scenarios. More specifically, the study aimed to evaluate the direction and magnitude of the potential impacts of climate change on aggregate agricultural output and other key agricultural indicators. Further, the study forecast changes in income for agricultural output for key subsectors under the A2 and B2 scenarios, from 2011 to 2050. It analysed the benefits and costs of the key adaptation strategies identified by Caribbean Governments.

The Global Agro-Ecological Zones Model, developed jointly by the Food and Agriculture Organization of the United Nations and the International Institute for Applied Systems Analysis, was used to determine potential changes in production capacities for the top five commodities (by volume) produced in the Caribbean. Estimates focused on sugarcane, rice, banana/plantain, cassava, yam, sweet potato and tomato. Estimates were calculated of percentage changes in annual average income, and changes in land suitability for specific crops.

Initial results indicated that significant losses in the estimated production of key agricultural crops with the exception of rice, was to be expected as a result of climate change. Under the A2 scenario, the estimated rice yield fell by approximately 3 per cent by the 2050s; however, under the B2 scenario, the potential rice yield would be expected to rise by approximately 2 per cent during the same period. The estimated output for all other crops was expected to fall by approximately 12 per cent under the A2 scenario by the 2050s, but only by 7 per cent over the same period.

Banana and plantain were expected to have the largest decline in estimated yield of all crops, by approximately 33 per cent under the A2 scenario, considered the Business as Usual case. When compared to B2, the fall in yield was still large, at almost 20 per cent. Rice was expected to have the best outcome, largely due to the CO2 fertilization effect of this C3 plant, versus the other crops, which are C4 plants. Across both rain-fed and irrigated systems, sugarcane was expected to have a 13 per cent drop in potential yield under A2 by the 2050s, and a 9.6 per cent drop under B2 over the same period. Cassava was projected to have a 22.2 per cent drop in potential yield under A2 by the 2050s and a 1.2 per cent drop under B2 for the same period. Yams were estimated to outperform cassava, with a 14.7 per cent drop in potential yield under A2 by the 2050s, but only a 6.3 per cent drop under B2 for the same period. Sweet potato was anticipated to experience a 2.4 per cent decline in potential yield by the 2050s under the Business as Usual scenario A2, and a 6.9 per cent decline under the B2

scenario. Tomatoes were likely to suffer significant declines in potential yield by the 2050s, of 28.1 per cent under A2 and 16.9 per cent under B2.

The relative impacts of climate change differed by crop under the A2 and B2 scenarios, but overall, the negative impacts appeared to be worse under A2, the longer the planning horizon. At a 1 per cent discount rate, the agricultural sector was expected to suffer losses of approximately US$ 4.2 billion for the Business as Usual scenario A2, and under half that amount, US$ 1.8 billion, under the B2 scenario.

Based on the current area of cultivated land there was variation by crop with regard to changes in the categories of crop suitability. By the 2050s, significantly more land was deemed as unsuitable for rain-fed cassava production using intermediate inputs, under the A2 scenario, relative to the B2. Under the A2 scenario, more than 70 per cent of the land that had been deemed as very highly suitable for irrigated sugarcane production using intermediate inputs was no longer in this classification by the 2050s, whereas, for the B2 scenario, approximately 50 per cent of land this classification was lost.

Ten key climate change adaptation strategies for the agricultural sector were suggested for implementation in the Caribbean, all of which have positive net benefits. The options with the highest net present value were the construction of water conservation systems such as on-farm ponds (US$ 115.283 billion), followed by mainstreaming climate change into all national policies (US$ 30.061 billion) and the establishment of an agricultural early warning system (US$ 2.205 billion).

Losses to the agricultural sector due to the impacts of sea-level rise were negligible; impacts were noted for Jamaica (US$ 3.9 million in losses in 2050) and the Bahamas (US$ 0.1 million losses in 2050).

I. Introduction

More and more, there is evidence that anthropogenic activities are having negative impacts on the Earth's climate. As a result, all countries are now seeking to determine the likely effect of joint action on the global commons and, more importantly, to find ways of reducing greater potential negative impacts, while preparing local communities to adapt in order to cope with, or even benefit from, projected climate change. Fortunately, many countries are already making modifications to reduce their emissions of greenhouse gases (GHG) in some economic sectors, through policy and legislative review. However, other countries are protecting their status quo vigorously, or are achieving very little reduction in their contribution to climate change. The final outcome will rely heavily on individuals and firms making adjustments to their economic behaviour, which may come at personal cost, although the aggregate benefit to society would vastly outweigh the sum of the individual costs.

In order to determine the impact of climate change on the agricultural sector in the Caribbean, a baseline period has been established. The Intergovernmental Panel on Climate Change (IPCC) *Special Report on Emissions Scenarios* (SRES) A2[1] and B2[2] scenarios have been used as the projected future climate for the Caribbean (IPCC, 2000). Using Atmosphere-Ocean General Circulation and Earth System Models, IPCC (2007) projected that global temperatures would rise. Under the A2 and B2 scenarios, it was expected that, relative to temperatures during 1980-1992, temperatures would rise globally by 3.4° Celsius (C) and 2.4° C, respectively, with a likely range of 2.0° C to 5.4° C, and 1.4° C to 3.8° C, respectively, by 2090-2099. Furthermore, global sea levels were expected to rise by between 0.23 metres and 0.51 metres under the A2 scenario, and between 0.2 metres and 0.43 metres under the B2 scenario over the same period.

Climate projections have been made for a number of regions worldwide, yet there has been very little consistency among Global Climate Models in their projections for the Caribbean on the potential changes in many climate variables, including rainfall. One of the key concerns—from a small island perspective—is the intensity, frequency and distribution of extreme events, such as

[1] The A2 storyline and scenario family describes a very heterogeneous world. The underlying theme is self reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in continuously-increasing population. Economic development is primarily regionally-oriented and per capita economic growth and technological change more fragmented and slower than other storylines.

[2] The B2 storyline and scenario family describes a world in which the emphasis is on local solutions to economic, social and environmental sustainability. It is a world with continuously increasing global population, at a rate lower than A2 and intermediate levels of economic development. While the scenario is also oriented towards environmental protection and social equity, it focuses on local and regional levels.

hurricanes. Model projections, to date, have not provided conclusive evidence of the patterns of these events that may occur in the future (IPCC, 1997).

In tropical, low-latitude regions of the Southern Hemisphere, the El Niño Southern Oscillation (ENSO) is a major factor in year-to-year climate variability, with a marked effect on rainfall patterns (IPCC, 1997). In most countries of the Caribbean, the tropical climate is characterized by an annual rainfall regime of pronounced wet and dry seasons. The present study analyses econometrically the projected impact of climate change on the agricultural sector of 16 Caribbean countries, namely: Antigua and Barbuda, the Bahamas, Barbados, Belize, Cuba, Dominica, the Dominican Republic, Grenada, Guyana, Haiti, Jamaica, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines, Suriname, and Trinidad and Tobago.

The agricultural sector analysis in the study has been confined to the crop subsector. This includes a combination of subsistence and commercial production. Crop-production data were not available disaggregated by level of technology (such as commercial, semi-commercial or subsistence), so that the specific impact of climate change on each of these subsectors could not be evaluated individually. Poor data availability for livestock production and prices over time hindered analysis of that subsector. Fisheries analysis has been covered in a concurrent study on the impact of climate change on the coastal and marine sector. The forestry subsector was not included in the study, as most countries in the Caribbean define their forestry resources outside the agricultural sector. Furthermore, while forestry management provides the basis for improved watershed services such as groundwater, the vast majority of farming in the Caribbean does not contain a silviculture component.

The agricultural sector has several links with other sectors. It is the largest user of water globally, so that changes in water availability through precipitation and groundwater storage, as well as changes in evapotranspiration[3] as the Earth's temperature rises, will have significant effects on water availability for plant growth and fruit development. It will also have effects on the length of the crop cycle, as well as on the potential start of the crop cycle. Furthermore, agriculture competes intensely for water with the tourism, industrial and residential sectors. The allocation of water to the agricultural sector will depend on the level of water resources in each country, but also—significantly—on the public sector allocation of water based on perceived importance of water to each sector.

The Caribbean agricultural sector uses non-renewable energy, and contributes to greenhouse gases such as methane (primarily via livestock production) and carbon dioxide (CO2). Links between the agricultural sector and tourism are weak, most of the food used in the tourism sector being imported from sources outside the Caribbean.

The main objective of the present study is to determine the value of impacts due to climate change on the agricultural sector in the Caribbean under the IPCC A2 and B2 SRES scenarios. The specific objectives are:

a) To collect relevant data on the socioeconomic status of the Caribbean, including the level and trends in the key economic drivers, livelihood characteristics, and drivers of development.

b) To evaluate the direction and magnitude of the potential impacts of climate change on the aggregate agricultural output and other key agricultural indicators.

c) To forecast the changes in income for agricultural output for key subsectors under the A2 and B2 scenarios, from 2013 to 2050.

d) To prioritize the key threats, based on established research and expert opinion.

[3] Evapotranspiration is the loss of water to the atmosphere by the combined processes of evaporation from the Earth's land surface and transpiration from plant tissues.

e) To create a detailed list of suitable adaptation strategies for the Caribbean.

f) To calculate the discounted costs of selected mitigation and adaptation strategies in the Caribbean, which have been identified by Caribbean Governments.

In the early part of the twentieth century, agriculture was the mainstay of all Caribbean economies. However, over the last 20 years, the contribution of agriculture to total gross domestic product (GDP) has fallen dramatically in most Caribbean countries. Guyana is the only country in the Caribbean Community (CARICOM) in which the contribution of agriculture to GDP exceeds 20 per cent. The agricultural sector in the Caribbean is a significant employer and, by extension, supports both directly and indirectly many farming families and communities.

II. Caribbean agricultural sector overview

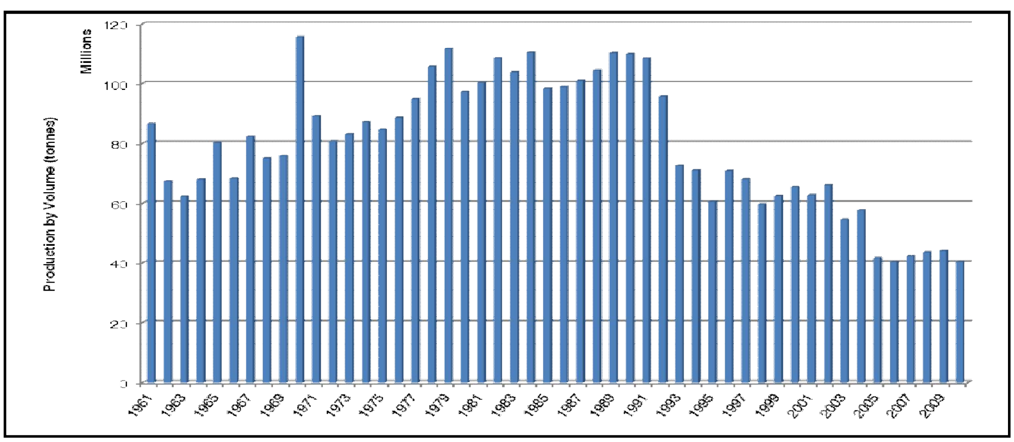
A. Crop subsectors

All Caribbean economies were based on the production of plantation crops, such as sugarcane and bananas. Between 1961 and 1989, total Caribbean crop production rose from approximately 87 million tonnes to approximately 110 million tonnes, with mild fluctuations around a steadily upward trend (figure 1). However, from 1990 onwards, there was an overall downward trend in total crop production, with huge declines in the 1990s so that, by 2010, total crop production fell to approximately 40 million tonnes, down by more than 60 per cent from the highs in production experienced in the 1980s. The initial movement in crop output is shown by the crop production index, developed by the Food and Agriculture Organization of the United Nations (FAO) (figure 2). The FAO crop production index shows that crop production has risen steadily since 1961, despite the fall-off in production. The livestock index fell slowly, yet fairly consistently, over the same period, which suggested that the volume of crop production increased relative to livestock production.

FIGURE 1

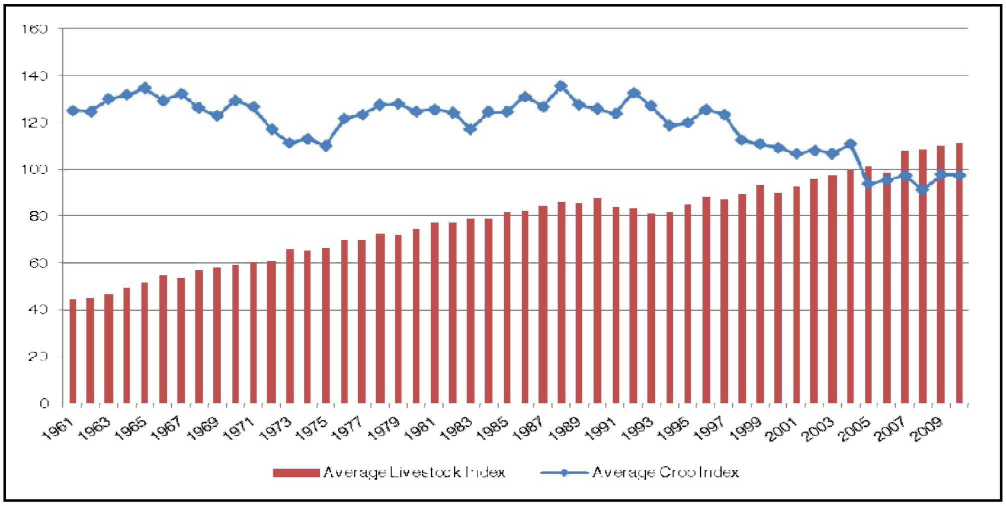
TOTAL CROP PRODUCTION BY VOLUME FOR THE CARIBBEAN, 1961-2010

(Millions of tonnes)



Source: Food and Agriculture Organization of the United Nations (FAO), "FAOSTAT – Production" [online database], [date of reference: October 2012] < http://faostat.fao.org/site/339/default.aspx>

FIGURE 2
AVERAGE CROP AND LIVESTOCK PRODUCTION INDICES FOR THE CARIBBEAN, 1961-2010 (2004-2006 = 100)

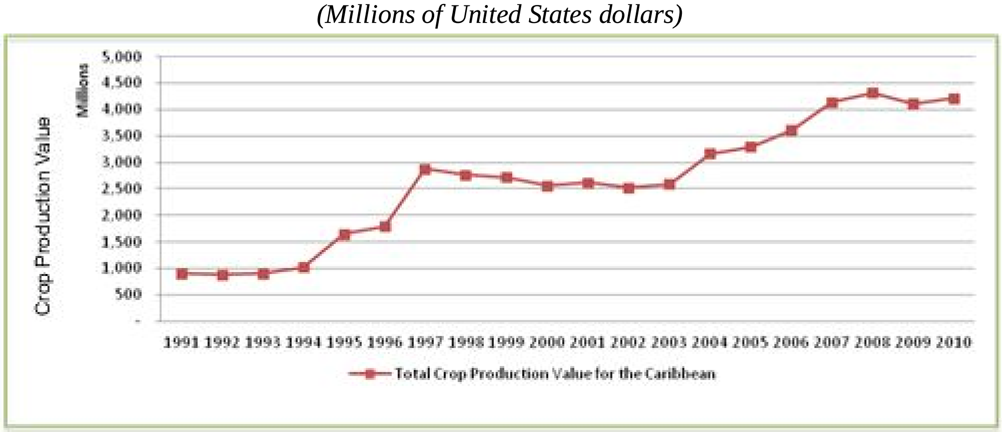


Source: Food and Agriculture Organization of the United Nations (FAO), "FAOSTAT – Production" [online database] [date of reference: October 2012] < http://faostat.fao.org/site/339/default.aspx>

1. Total value of crop production for the Caribbean

Overall, crop production values quadrupled in the Caribbean from 1991 to 2010 (figure 3). In 1991, crop production value was under US$ 1 billion. Crop production value remained relatively stable in the early- to mid- nineteen-nineties. Thereafter, values increased to approximately US$ 3 billion, and stayed around that value until 2003. Subsequently, crop production values increased again steadily so that, by 2008, crop production values exceeded US$ 4 billion, and have remained fairly constant to 2010.

FIGURE 3
TOTAL CROP PRODUCTION VALUE FOR THE CARIBBEAN 1991-2010
(Millions of United States dollars)

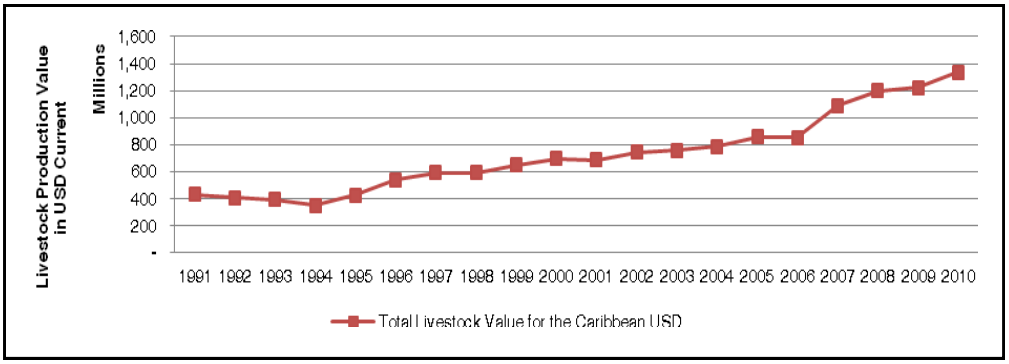


Source: Food and Agriculture Organization of the United Nations (FAO), "FAOSTAT – Production" [online database] [date of reference: October 2012] < http://faostat.fao.org/site/339/default.aspx>; Country data

2. Total value of livestock production for the Caribbean

The value of primary livestock production tripled in the Caribbean between 1991 and 2010, and showed a steady upward trend over time, with only a few years showing declines in the value of output (figure 4).

FIGURE 4
TOTAL LIVESTOCK PRODUCTION VALUE FOR THE CARIBBEAN, 1990-2010
(Millions of United States dollars)



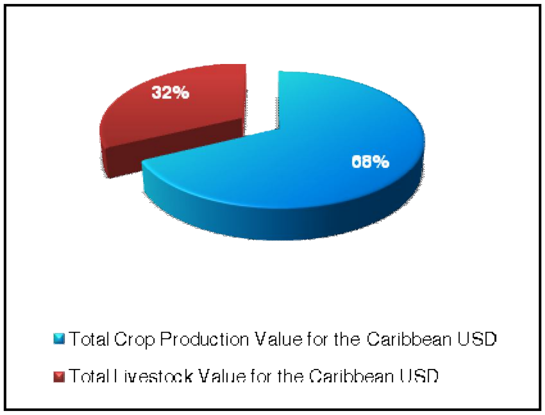
Source: Food and Agriculture Organization of the United Nations (FAO), “FAOSTAT – Production” [online database] [date of reference: October 2012] < http://faostat.fao.org/site/339/default.aspx>; Country data

The biggest growth in value has occurred in more recent times, from 2006 to 2010. This growth rate has exceeded that of crop production over this same period, indicating that, should this trend continue, the share of livestock value in total agricultural output would rise relative to crop value, and the livestock sector would become relatively more valuable over time.

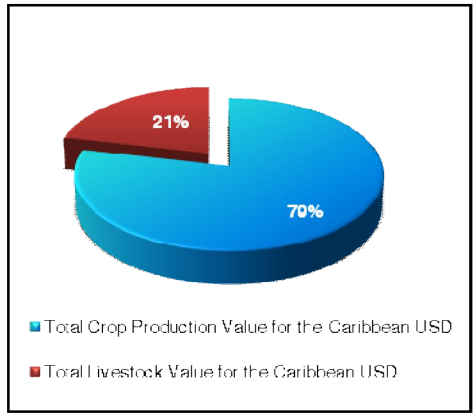
3. Shares of crop and livestock values for the Caribbean

The three charts in figure 5 show changes in the shares of Caribbean crop and livestock production in selected years. Between 1991 and 2000, the value of the share of livestock production fell from 32 per cent to 21 per cent but, by 2010, the value of this share increased to 24 per cent of the value of total agricultural output.

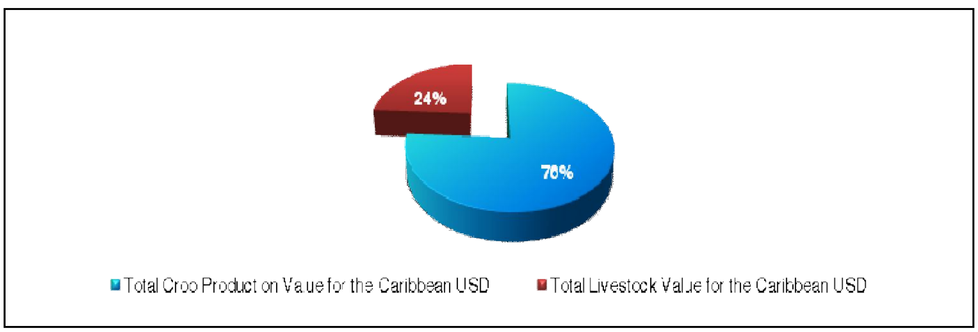
FIGURE 5
CROP AND LIVESTOCK SHARE VALUES IN THE CARIBBEAN
(Percentage of the value of total output)



(a) 1991



(b) 2000



(c) 2010

Source: Author's calculations based on FAOSTAT production and price data

Historical production values of crops and livestock from 1991 to 2010 are shown in annex 1.

B. Major commodities and commodity groups

In 2010, a total of 40,500,764 tonnes of crops were produced in the Caribbean (table 1), of which the top 10 crops accounted for 84.3 per cent of total output. The primary commodity produced was sugarcane (which accounted for 57.7 per cent of total output), followed by paddy rice (5.6 per cent) and bananas (4.3 per cent). These three commodities were produced primarily for extraregional export and, therefore, represented significant earners of foreign exchange. Most of the other commodities, particularly root crops, plantains and vegetables, were consumed largely in domestic markets, or traded intraregionally. The relative share of commodity groups has changed dramatically over the last 50 years in the Caribbean. Figures 6(a)-6(d) show how the share of the sugarcane crop has declined relative to other commodity groups over time.

TABLE 1
TOP TEN CROPS PRODUCED IN THE CARIBBEAN BY VOLUME, 2010
(Tonnes and percentage)

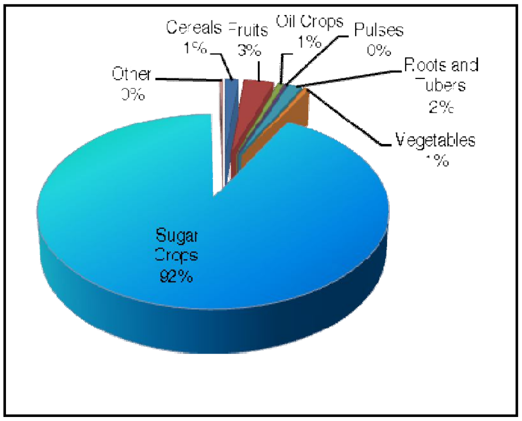
Crop	Tonnes	Share of total production (%)
Sugar cane	23 374 638	57.7
Rice, paddy	2 251 610	5.6
Bananas	1 741 972	4.3
Plantains	1 280 205	3.2
Cassava	1 263 437	3.1
Vegetables, fresh, nes*	1 014 545	2.5
Yams	936 741	2.3
Tomatoes	789 857	2.0
Mangoes, mangosteens, guavas	737 190	1.8
Sweet potatoes	732 003	1.8
Total share		84.3
All crops	40 500 764	

Source: Food and Agriculture Organization of the United Nations (FAO), "FAOSTAT – Production" [online database] [date of reference: October 2012] < http://faostat.fao.org/site/339/default.aspx>

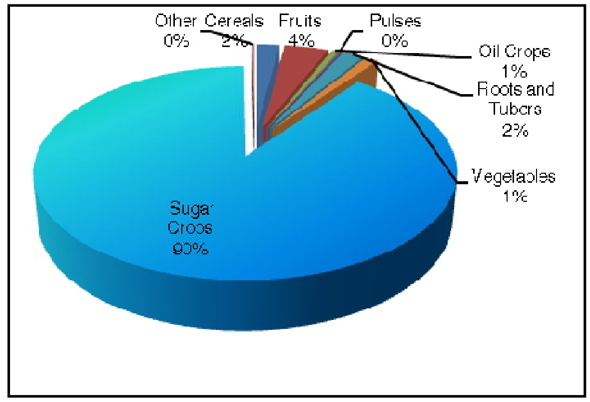
Note: *nes = not elsewhere specified.

In 1961, sugar crops which for the Caribbean, is represented by sugarcane, accounted for 92 per cent of total crop production, by weight. This was followed by fruit (3 per cent), roots and tubers (2 per cent), oil-bearing crops (noted as oil crops in figure 6) (1 per cent), then vegetables (1 per cent). From 1961 to 1990, the shares of these crop groups (based on the FAO classification) remained largely the same, with sugar crops leading production with a 90 per cent share of total output. However, by 2000, with the declining market access of sugarcane to the European Union, the share of sugar crops fell to 76 per cent. By 2010, this share fell even more, to 58 per cent. Even though sugar crops have continued to dominate, by volume, the total output in the Caribbean, other crop categories have now shown increasing importance. The sugar crop in 2010 was followed by fruit (15 per cent), roots and tuber (9 per cent), vegetables (8 per cent) and cereals (largely rice) (7 per cent).

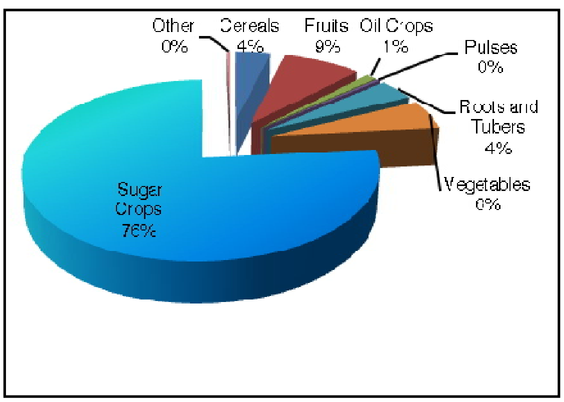
FIGURE 6
SHARE BY PRODUCTION VOLUME OF KEY CROP GROUPS IN THE CARIBBEAN
(Percentage)



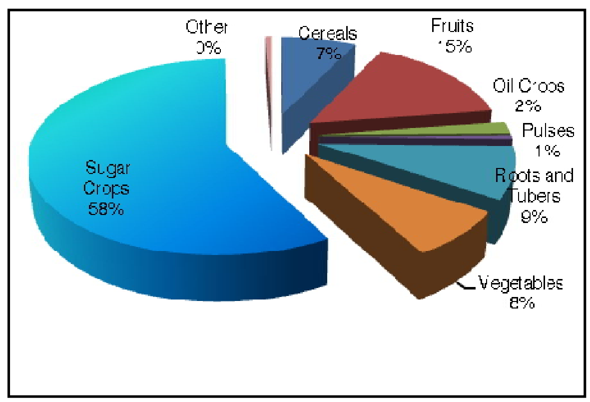
(a) 1961



(b) 1980



(c) 2000



(d) 2010

Source: Author's calculations based on FAOSTAT production data

While the share of oil-bearing crops, such as coconuts, has declined over time, the shares of fruit, roots and tubers and vegetables have increased table 2).

However, the increasing share of non-sugar crops has disguised the sluggish increases in volume. For example, even though there was an approximately fivefold increase in the share of fruit, absolute production increased little more than twofold (only 116 per cent) from 1961 to 2010, due to shrinking overall crop production volume over the same period. The top four commodities produced in each Caribbean country in 2010, ranked by value, are shown in annex 2.

Locally-produced chicken, pig or cattle meat are among the top four individual commodities produced, by value, for all Caribbean countries, excepting Dominica, Grenada, and Saint Vincent and the Grenadines.

TABLE 2
VALUE OF CROP PRODUCTION BY CATEGORY AND SHARE IN THE CARIBBEAN, 1961, 1990 AND 2010
(Tonnes and percentage)

Rank	1961	1990	2010
1st	Sugar crops	Sugar crops	Sugar crops
Volume (tonnes)	79 629 549	98 506 200	23 374 638
Share	92 per cent	90 per cent	58 per cent
2nd	Fruits	Fruits	Fruits
Volume (tonnes)	2 878 984	5 261 372	6 205 817
Share	3 per cent	5 per cent	15 per cent
3rd	Roots and tubers	Roots and tubers	Roots and tubers
Volume (tonnes)	1 353 562	1 962 217	3 510 010
Share	2 per cent	2 per cent	9 per cent
4th	Cereals	Cereals	Vegetables
Volume (tonnes)	1 278 374	1 799 011	3 124 005
Share	1 per cent	2 per cent	8 per cent
5th	Oil-bearing crops	Vegetables	Cereals
Volume (tonnes)	571 198	1 197 268	3 006 079
Share	1 per cent	1 per cent	7 per cent

Source: Author's calculations based on FAOSTAT online database

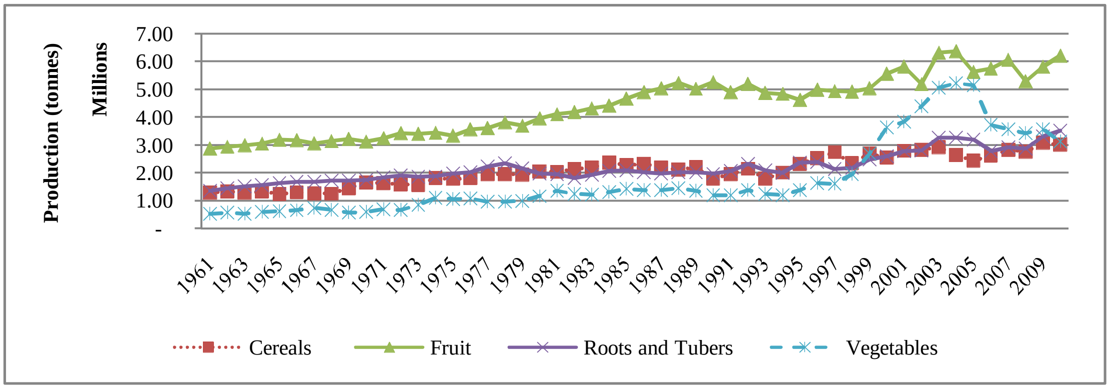
1. Changes in crop production

a) Cereals, fruit, vegetables, and roots and tubers

Cereal production in the Caribbean is comprised mainly of rice. Volumes increased fairly steadily from 1961 to 2010, with the highest harvest, at approximately 3.31 million tonnes, reaped in 2009 (figure 7). Most of the rice production occurred in Guyana, where rice was produced largely for export to the European Union. In 1961, cereal production was only 1 per cent of output by volume; by 2010, cereals accounted for 7 per cent of total harvest and were the fifth largest crop group. Cereal production in 2010 was 3.12 million tonnes, which was 144.37 per cent higher than 1961 harvests.

Overall, fruit production in the Caribbean has been expanding steadily, made up mainly of bananas, plantains, mangoes and oranges. Volumes increased moderately, from 2.88 million tonnes in 1961 to a peak of 6.37 million in 2004 (figure 7). From 2004, fruit production experienced high inter-annual variation. By 2010, fruit production was at 6.21 million tonnes, up approximately 116 per cent from the 1961 levels, with the biggest fruit harvest, at approximately 3.31 million tonnes, in 2009 (figure 7). Fruit maintained its rank as the second largest crop group from 1961 to 2010: between 1961 and 2010, the share of fruit production in total crop production increased dramatically, from 3 per cent in 1961 to 15 per cent in 2010, the biggest share increase by any crop group over the period.

FIGURE 7
CEREAL, FRUIT, VEGETABLES AND ROOTS AND TUBERS PRODUCTION FOR THE CARIBBEAN, 1961-2010
(Millions of tonnes)



Source: Food and Agriculture Organization of the United Nations (FAO), “FAOSTAT – Production” [online database] [date of reference: October 2012] < http://faostat.fao.org/site/339/default.aspx>

Roots and tubers production increased progressively from 1961 with very little variability (figure 7). Production peaked in 2010 at 3.51 million tonnes, an overall increase of approximately 159 per cent of 1961 output. Harvests in this category were primarily of cassava, yam and sweet potato, in order of importance. Initially, vegetable production had gradual increases from 1961-1997 (figure 7). Subsequently, production increased considerably. Between 1997 and 2004, vegetable production in the Caribbean more than tripled, increasing from 1.61 million tonnes in 1997 to 5.22 million tonnes by 2004. However, after 2004, production fell drastically, so that, by 2010, output stood at 3.12 million tonnes, which was a 489 per cent increase over 1961.

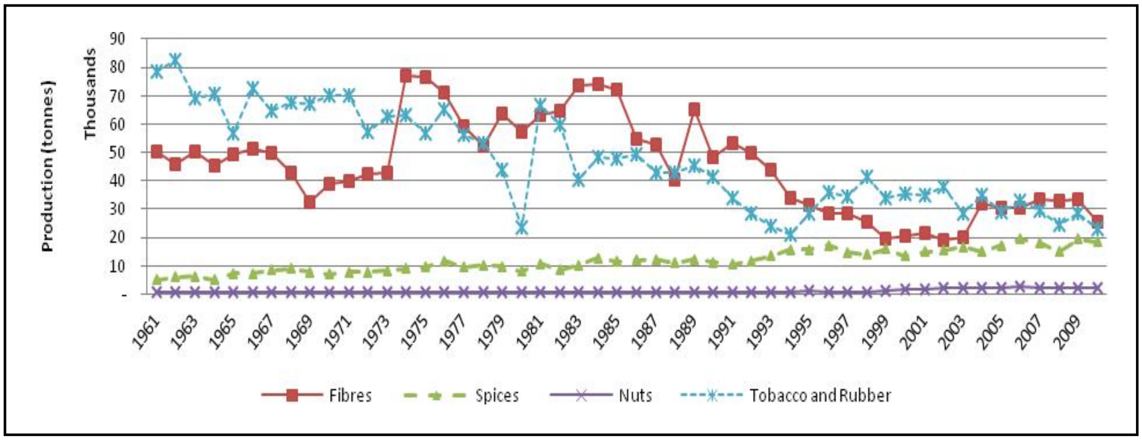
b) Fibre, spices, nuts, tobacco and rubber

Fibre production in the Caribbean was comprised mainly of agave fibre, jute and sisal from Cuba, the Dominican Republic and Haiti. Output grew by approximately 20 per cent between 1961 and 1973, then spiked by 80 per cent between 1973 and 1974 (figure 8). Thereafter, production fluctuated widely, but had a downward trend so that, by 2010, production was at 25 320 tonnes, almost half of the 50 316 -tonne level of 1961.

In general, spice and nut production in the Caribbean has been minor, even with volumes more than tripling from 1961 to 2010. Spice production stood at 18 506 tonnes in 2010, up from 5 116 tonnes in 1961 (figure 8). Likewise, nut production was at 2 363 tonnes in 2010, up from 738 tonnes in 1961.

The tobacco and rubber crop group was dominated by Cuban tobacco production. Despite the high value of the tobacco crop, output fell drastically, from 78,743 tonnes in 1961 to 23 258 tonnes by 2010.

FIGURE 8
FIBRE, SPICES, NUTS, TOBACCO AND RUBBER PRODUCTION FOR THE CARIBBEAN, 1961-2010
(Thousands of tonnes)

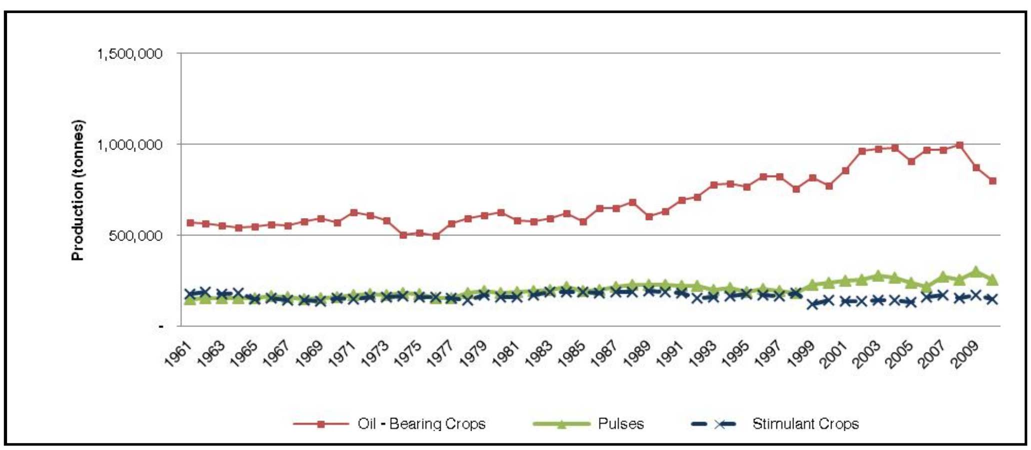


Source: Food and Agriculture Organization of the United Nations (FAO), "FAOSTAT – Production" [online database] [date of reference: October 2012] < http://faostat.fao.org/site/339/default.aspx>

c) Oil-bearing crops, pulses and stimulant crops

Oil-bearing crop production in the Caribbean was comprised mainly of coconuts from all countries. Over time, output rose steadily, from 571,198 tonnes in 1961 to a peak of 999,080 tonnes in 2008 (figure 9). However, since then, production has fallen successively, in 2009 and 2010, down to 799,845 tonnes. This decline was due, in part, to the spread of the Red Palm Mite disease, which decreased the productivity of trees. The production of pulses increased by 69 per cent between 1961 and 2010, but pulses have remained a relatively minor crop group. Stimulant crops, made up largely of cocoa and coffee, have also remained a relatively minor crop group, with production falling by 17 per cent between 1961 and 2010, when production in the Caribbean was only 148,153 tonnes.

FIGURE 9
OIL-BEARING CROPS, PULSES AND STIMULANT CROP PRODUCTION FOR THE CARIBBEAN, 1961-2010
(Metric tonnes)

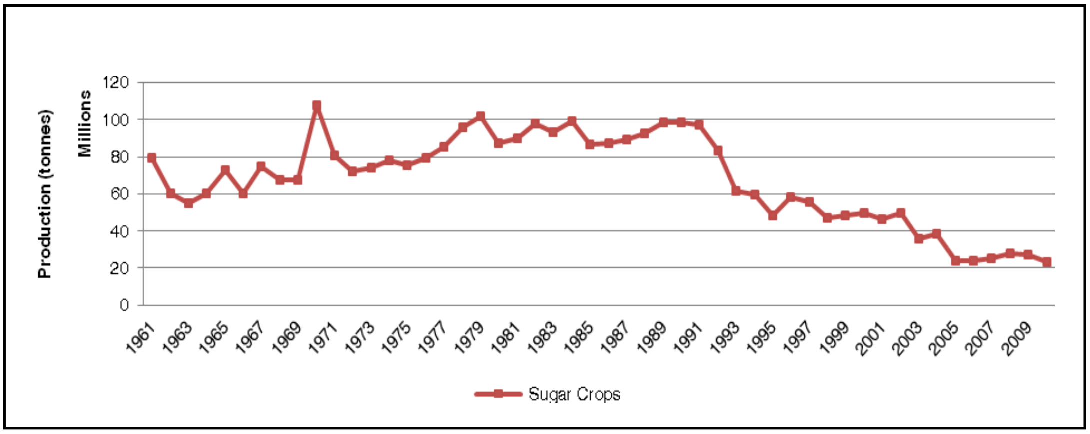


Source: Food and Agriculture Organization of the United Nations (FAO), "FAOSTAT – Production" [online database] [date of reference: October 2012] < http://faostat.fao.org/site/339/default.aspx>

d) Sugar crops

From 1961 to 1979, sugar crops, mainly sugarcane, had a slow upward trend in production (figure 10), up to 101.75 million tonnes in 1979. However, production levelled off in the 1980s. From the early 1990s, on-farm productivity at many sugar estates, both State-owned and private, declined sharply despite increases in on-farm mechanization and input use. This resulted in a steep downward trend so that, by 2010, sugar crop production was 23.37 million tonnes.

FIGURE 10
TOTAL SUGAR CROP PRODUCTION FOR THE CARIBBEAN 1961-2010
(Millions of tonnes)



Source: Food and Agriculture Organization of the United Nations (FAO), “FAOSTAT – Production” [online database], [date of reference: October 2012] < http://faostat.fao.org/site/339/default.aspx>

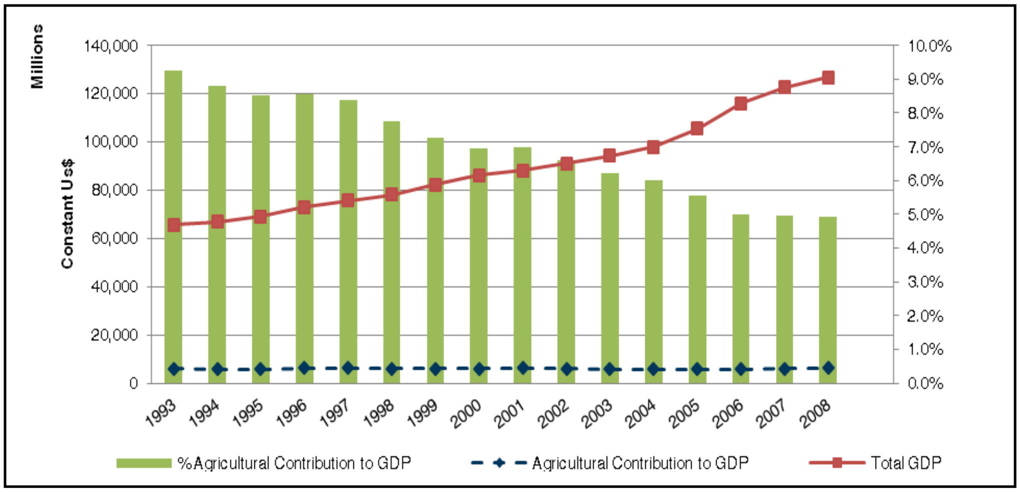
C. Agricultural sector income and total Caribbean gross domestic product

While the total gross domestic product of the Caribbean rose significantly and steadily from 1993 to 2008, the value of the agricultural sector contribution to GDP, in constant dollar terms, remained relatively flat, so that the percentage contribution of the agricultural sector to total GDP fell markedly, from approximately 9 per cent in 1993, to approximately 5 per cent in 2008 (figure 11).

Despite its falling percentage contribution to Caribbean income, the agricultural sector has continued to be a major employer. In 1994, approximately 30 per cent of the total labour force was employed in agriculture (table 3). By 2008, although this figure had fallen to approximately 20 per cent of the total labour force, it still represented a significant proportion of total employment.

Limited data by country, disaggregated by gender, were available to determine the percentage of female workers in the agricultural sector (annex 3). Males normally accounted for more than 90 per cent of agricultural labour in each country. Haiti had the highest contribution of women workers, approximately 37 per cent female labour in 1999, down from approximately 53 per cent in 1980.

FIGURE 11
AGRICULTURAL SECTOR CONTRIBUTION TO CARIBBEAN GROSS DOMESTIC PRODUCT
(millions of United States dollars)



Source: Author's calculations based on the World Bank online database

TABLE 3
AGRICULTURAL LABOUR FORCE AND TOTAL AGRICULTURAL EMPLOYMENT IN THE CARIBBEAN, 1994 AND 2008
(Percentage)

	Agricultural labour force	Total labour force	Agricultural employment (per cent)
1994	3 954 081[1]	12 980 194	30.5
2008	3 579 306[2]	16 364 343	21.9

Source: Author's calculations based on the World Bank online database

Notes: No agricultural employment or total labour force data were included for Antigua and Barbuda, the Commonwealth of Dominica, Grenada, or Saint Kitts and Nevis.

[1] includes data for 12 countries in 1994, except Guyana (1997), Haiti (1990) and Saint Vincent and the Grenadines (1991).

[2] includes data for 12 countries for 2008, except Barbados (2004), Belize (2005), Guyana (2002), Haiti (1999), Saint Lucia (2004), Saint Vincent and the Grenadines (2001) and Suriname (2004).

D. Land and water resources

Caribbean agricultural land area increased from 9 634 thousand hectares in 1961 to 13 483 thousand hectares in 2009 (table 4). However, in some countries, there was a significant fall in agricultural area (not shown), as well as sharp declines in forested areas. The data available on the size of irrigated areas were poor but, from anecdotal evidence, the proportion of areas under irrigation was minor, and was primarily for vegetable crops when nearby water sources were available.

TABLE 4
CARIBBEAN LAND ALLOCATION, SELECTED YEARS
(Thousands of hectares)

	1961	1965	1970	1975	1980	1985	1990	1995	2000	2005	2009
Land area	58 808	58 808	58 808	58 822	58 813	58 813	58 813	58 813	58 813	58 717	58 717
Agricultural area	9 634	10 698	11 294	12 107	12 759	13 032	13 506	13 532	13 364	13 305	13 483
Agricultural area irrigated	-	-	-	-	-	-	-	-	-	0.04	0.4
Temporary crops	-	-	-	-	-	-	-	-	-	4	4
Permanent crops	941	980	1 136	1 174	1 240	1 295	1 459	1 556	1 554	1 396	1 372
Permanent meadows and pastures	4 922	5 747	5 435	5 669	5 870	5 931	6 176	5 743	5 741	5 776	5 866
Forest area	-	-	-	-	-	-	36 738	36 873	37 008	37 216	37 305

Source: Food and Agriculture Organization of the United Nations (FAO), "FAOSTAT – Resources" [online database] [date of reference: October 2012] < http://faostat.fao.org/site/377/default.aspx#ancor>

"-" not available

The source of water being used in each Caribbean country, in general, and for agriculture in particular, varied from country to country (table 5). In most cases, surface water was the key water source for the agricultural sector. In some countries which were very water-scarce, such as Antigua and Barbuda, desalination was used. However, this practice was not widespread, because of the high start-up investment costs.

TABLE 5
PRIMARY WATER SOURCES IN THE CARIBBEAN
(Thousands of hectares)

Country	Surface	Groundwater	Desalination	Notes
Antigua and Barbuda	X	X	X	Desalination provides 60 per cent water in the rainy season and 75 per cent water in the dry season
The Bahamas		X		Little surface water
Barbados		X	X	
Belize	X	X		Surface provides 70 per cent water in urban areas. Groundwater provides 95 per cent of freshwater supply in rural areas.
Cuba	-	-	-	
Dominica	X			
the Dominican Republic				
Grenada	X	X		Surface provides 90 per cent of water supply.
Guyana	X	X		
Haiti	X	X		
Jamaica	X	X		Groundwater provides 92 per cent of water supply to all sectors.
Saint Kitts and Nevis	X	X		Surface water is the main supply for St. Kitts. Groundwater is the main supply for Nevis.
Saint Lucia	X	X		Surface water is the main supply.
Saint Vincent and the Grenadines	X			
Suriname	X	X		
Trinidad and Tobago	X	X	X	

Source: Data compiled by Author

Caribbean countries are more vulnerable than many other least developed countries (LDCs) when hurricanes and tropical storms strike, as the coastal exposure is very high relative to land mass (Deep Ford and Rawlins, 2007). Hurricanes not only cause severe damage, but occur with high frequency. Vulnerability is greater, as a significant proportion of the arable land in the Caribbean lies on steep slopes, which makes it susceptible to soil erosion. Compared to LDCs, the per capita arable land availability of the Caribbean is about half, which, given the difficulty of achieving economies of scale due to small populations, means the productivity of agricultural production has declined over time.

> "As barriers to world trade are dismantled, the most competitive producers increase their market share. Caribbean economies have low levels of competitiveness due to higher unit costs of production (caused by scarce resources, high transport costs, low economies of scale, small size of firms, etc.) and thus their market share will decrease under the new conditions."[4]

Also, as a result of limited production diversity, most of the inputs needed for agricultural production, such as machinery, fertilizers and pesticides, have been imported, which has increased the vulnerability of the agricultural sector.

[4] J.R. Deep Ford and G. Rawlins, "Trade policy, trade and food security in the Caribbean", *Agricultural trade policy and food security in the Caribbean: Structural issues, multilateral negotiations and competitiveness*, J.R. Deep Ford, C. Dell'Aquila and P. Conforti (eds.), Rome, Deep Ford and Rawlins, 2007.

III. Climate change impacts on agriculture

Potential impacts of climate change on agriculture can be positive or negative, and are associated with different levels of confidence. A summary of key potential climate impacts are shown in table 6. Many early climate models had predicted very severe impacts on the world's food supply, whereas more recent models have indicated that there will be very negative impacts in some areas, especially in the tropics, in areas vulnerable to changes such as sea-level rise, and in areas heavily dependent on rain-fed agriculture (mainly rural areas) for the sustenance for their livelihoods (Antle, 2008). In many of these cases, incomes are very low, and dependence on agriculture, high. However, it is also likely that there will be positive impacts, particularly in upland tropical and temperate regions. So, increases in food supply in some areas could offset the negative impacts in other areas, via price reductions and international trade. Globally, the overall impacts of climate change may well be positive (Antle, 2008).

Cline (2007), however, indicated that the aggregate world agricultural impacts of climate change would be negative, though moderate, by late in the twenty-first century, which contradicted the view that world agriculture would actually benefit in the aggregate from business-as-usual global warming over that horizon. What was consistent—and key for the Caribbean—was that his work, like previous research, agreed that the damage would be disproportionately concentrated in developing countries.

TABLE 6
POTENTIAL GLOBAL CLIMATE CHANGE EFFECTS ON AGRICULTURAL PRODUCTION

Climate and related physical factors	Expected direction of change	Potential impacts on agricultural production	Confidence level of the potential impact
Atmospheric CO_2	Increase	Increased biomass production and increased potential efficiency of physiological water use in crops and weeds Modified hydrologic balance of soils due to carbon/nitrogen ratio modification Changed weed ecology with potential for increased weed competition with crops	Medium
		Agro-ecosystems modification	High
		Nitrogen cycle modification	High
		Lower-than-expected yield increase.	Low
Atmospheric CO_3	Increase	Crop yield decrease	Low
Sea level rise	Increase	Sea-level intrusion in coastal agricultural areas and salinization of water supply	High
Extreme events	Poorly known, but significant increased temporal and spatial variability expected, increased frequency of floods and droughts	Crop failure Yield decrease Competition for water	High
Precipitation intensity	Intensified hydrological cycle, but with variations across countries	Changed patterns of erosion and accretion Changed storm impacts Changed occurrence of storm flooding and storm damage Increased waterlogging Increased pest damage	High
Temperature	Increase	Modifications in crop suitability and productivity Changes in weeds, crop pests and diseases Changes in water requirements	High
	Differences in day-night temperature	Changes in water requirements Modifications in crop productivity and quality	Medium
Heat stress	Increases in heat waves	Damage to grain formation, increase in some pests	High

Source: A. Iglesias and others, *Impacts of climate change in agriculture in Europe: PESETA-Agriculture Study*, European Commission, Joint Research Centre, 2009

IV. Literature review

Several approaches have been used to assess the impact of climate change on the agricultural sector. In some cases, impacts were measured in relation to specific dominant commodities, and in other cases, the impact was measured at country level. Most of the models can be classified as one of the following:

a) Agroecological models

b) Agroeconomic models

c) Ricardian models

d) Panel/fixed effects models

e) Crop production functions

f) Integrated assessment models

A. Agroecological zone models[5]

In agroecological zone models, crops were categorized into various agroecological zones and then yields predicted. These models combined crop simulation models with land-use decision analysis, and modelled changes in inputs and climate variables to assess changes in agricultural production. They assumed that land use could shift from one agroecological zone classification to another with changes in environmental conditions (Cline, 2007). The agroecological zone model examined changes in agroecological zones and crops as climate changed, and predicted the effects of alternative climate scenarios on crop yields. Economic models then used the projected changes in yields to predict overall supply effects.

Crop simulation models, including Decision Support System for Agrotechnology Transfer (DSSAT), The World Food Studies (WOFOST) model, and the revised FAO Methodology for Crop

[5] Also known as the crop-suitability approach.

Water Requirements (CROPWAT), have been widely used, taking the interaction of plant respiration and photosynthesis relationships to estimate the potential effects of changes in soil, plant and climate data, together with experimental data, to determine potential impacts on plant growth (Rivero Vega, 2008). The AEZ models showed the expected changes in crop growth as a result of shifts in the agroecological zones. Recent work using that kind of model was done by Fischer and others (2005), who used the Global Agroecological Model (GAEZ), Falloon and Betts (2010), and Alcamo and others (2007) who also used the GAEZ model. One of the biggest advantages associated with agroecological zones were that the geographical distribution of the zones in [many] developing countries had been published (Mendelsohn and Dinar, 1999). However, there were still many problems. The climatic zones usually represented large temperature categories, so that subtle shifts within a zone had no effect, whereas a small shift from one zone to another had dramatic consequences. Furthermore, the effects of soils and climate were computed independently, which ignored the interrelationship between these variables. As with the agroeconomic models the need for researchers to account explicitly for adaptation has been the weakness of this type of model.

Some of the models have been developed on a global scale. Golub, Hertel and Sohngen (2007) estimated a linked supply-and-demand model for global land using a dynamic general equilibrium model, that predicted economic growth in each region of the world based on exogenous projections of population, skilled and unskilled labor, and technical change, and that differentiated the demand for land by agroecological zone (AEZ).

The GAEZ model, developed jointly by FAO and the International Institute of Applied Science Analysis (IIASA), has been based on more than 30 years of work, and the newest version of the programme was launched in 2012. That model has now brought together many elements of agroecological zone modelling that former models had not included. Elements of the model include climate data, socioeconomic data such as population density, access to market, soil type, slope, water retention capacity and susceptibility to pest and diseases. It then compared historical production potential to 12 different GCM scenarios developed under IPCC.

B. Agronomic-economic crop models

Often, the outputs from crop simulation and agroecological zone (AEZ) models have been used to feed into economic models. In this way, agronomic-economic crop models are formed. For example, the GAEZ model was used in conjunction with a water-resource and a population model to estimate the impacts of water stress on food production (Alcamo and others, 2007). Likewise, it has been linked to a Basic Food System Model (Fischer and others, 2005) to determine possible impacts of climate change on food production and world food trade. Some of the crop growth data may be obtained from controlled experimentation settings which, when used, have limited the potential to replicate potential responses under normal field conditions This approach to modelling climate change impacts in agriculture has used well-calibrated crop models from carefully-controlled experiments, in which crops were grown in field or laboratory settings that simulated different levels of precipitation, temperature and carbon dioxide. Under these conditions, farming methods were not allowed to vary. Moreover, farmers' adaptation to changing climate could not be captured in these models. Scientists were able to estimate the yield response of specific crops to various conditions. The presumed changes in yields from the agronomic model were fed into an economic model, which determined crop choice, production, and market prices.

Rosenzweig and Parry (1994) predicted that the doubling of atmospheric carbon would have only a small, negative effect on global crop production, but that the effects would be more pronounced in developing countries. Cline (2007), using various global circulation models, predicted significant overall falls in general yields in sub-Saharan Africa. Parry and others (2004) used this approach to estimate the potential impacts of climate change on global food production for the A1FI, A2, B1, and B2 IPCC climate change scenarios developed from the Hadley Centre Coupled Model, version 3

(HadCM3) global climate model. Finger and Schmid (2007) used an agronomic model to analyse corn and winter wheat production on the Swiss Plateau with respect to climate change scenarios. Yield functions were modelled by Furuya, Kobayashi and Meyer (2009), using subsidized producer prices and a time trend, in addition to temperature and precipitation variables.

C. Ricardian models[6]

Ricardian models use econometric analysis to estimate the relationship between rents from farms and key climate variables. This assessment is based on farm-level data of output values as dependent on output prices, labour costs, the level of capital investment, climate variables such as rainfall and temperature, and soil characteristics. Since farm-level data are used, the impacts of climate change in the Ricardian model are determined from the changes in farm output from farms which are located in a wide variety of climatic zones (with distinct variations in soil and climate parameters). These models assume that, as the costs of inputs change, producers maximize rents (or profits) by changing production patterns, a behaviour which reflects an adaptation to changes in climatic conditions (Patt and others, 2010). Thus is adaptation implicitly incorporated, whereby producers can use a number of approaches, such as changing the type of crops or livestock farmed, changing crop varieties or livestock breeds, changing sowing times, or changing their production systems (by employing additional, and/or different, hard or soft technologies). One key advantage of this approach is that, if land markets are operating properly, prices will reflect the present discounted value of land rents into the infinite future (Deschenes and Greenstone, 2006).

Many authors, to date, have focused on the projected response of agricultural systems that are either rain-fed or irrigated, primarily for agricultural systems in Africa (Kurukulasuriya and Mendelsohn, 2008a; Kurukulasuriya and Mendelsohn, 2008b), Sri Lanka (Seo, Mendelsohn and Munasinghe, 2005; Deressa and Hassan, 2009; Molua and Lambi, 2007; Deressa, Hassan and Poonyth, 2005; Maddison, Manley and Kurukulasuriya, 2007; Seo and Mendelsohn, 2006; Kurukulasuriya and others, 2006), Latin America (Seo and Mendelsohn, 2008; Seo and Mendelsohn, 2007), and the United States of America (Schlenker, Hanemann and Fisher, 2006). Studies in Zimbabwe by Mano and Nhemachena (2007), which utilized surveys of 700 smallholder farm households, found that net farms revenues were affected negatively by temperature increases and reductions in rainfall. Seo, Mendelsohn and Munasinghe (2005) found similar temperature and precipitation effects in Sri Lanka. Sensitivity analysis showed that net farm incomes of farms which utilized rain-fed systems were very sensitive—relative to irrigated farms—to changes in these climatic variables. These findings support the use of irrigation as an important adaptation strategy in the face of climate change. It was discovered that farmers in Zimbabwe were already adapting to climate change by planting drought-resistant crops, changing planting dates, and using irrigation.

One key criticism of the model has been that, as it was a partial equilibrium model, it included potential price adjustments that might occur as producers adapted (Patt and others, 2010). In addition, damages might be understated (as potential price drops were ignored) and benefits could be overstated (as increased supply values were inflated) (Mano and Nhemachena, 2007). Secondly, because it was a static model, it did not consider the transaction costs incurred in the adaptation process (Patt and others, 2010). Thirdly, the Ricardian model might not include other variables that were also expected to affect net farm incomes, such as market access and soil quality, but for which data may not be available. In such cases, the model might be subject to misspecification errors. Fourthly, this approach could not measure the effects of variables such as CO2 that did not vary across space (Seo, Mendelsohn and Munasinghe, 2005). Another flaw of the Ricardian model was that, being static, it assumed that technology, policy and land use (which all have significant impacts on farmers' production decisions) did not change.

[6] These are cross-sectional reduced form hedonic pricing models.

D. Panel/fixed effects models

The Fixed Effects model has been widely used in the United States of America, with analysis based on state- or county-level fixed effects. It uses that same overall approach of the Ricardian model, but has extended from a cross-sectional analysis to a panel data approach (Polsky, 2004; Deschenes and Greenstone, 2006). The main outcome in the United States-based studies was that the predicted increases in temperature and precipitation would have little effect on yields among the key crops (maize, soybeans and wheat), even though there were significant changes across States, with some States gaining, and others losing from the effects of climate change.

Instead of using land values as the dependent variable, it has been assumed that changes in farm profits were permanently embodied in land values (Deschenes and Greenstone (2004; 2006; 2007). In addition, Deschenes and Greenstone (2006) noted that this model differed from the Ricardian approach in that the estimated parameters of this model did not include the influence of all unobserved time invariant factors, based on an assumption of additive separability.

E. Production function models

The production function approach is the least common approach used to model the impacts of climate change on agricultural outputs. However, analyses using this approach have been undertaken in a number of countries. In general, crop output (by volume) was determined as a function of technical inputs (land, labour capital) and climate inputs. Quiroga, Gómez and Iglesias (2005) estimated the production of wheat, grapes, olives and oranges in Spain using this approach where, given production over various agro-climatic zones, the impact of maximum, minimum and mean temperature was observed, as well as periods of below-average rainfall. In China, JieMing, WenJie and DuZheng (2007) evaluated the impact of changes in climate on grain yields, using a drought index together with a climate-input indicator to analyse the relationship between the index and yield.

In Mexico, Gay and others (2006) analysed the impact of climate change on coffee production. Their model used mean seasonal temperature, mean seasonal precipitation, and the seasonal variance of climatic variables. In addition, international and local coffee prices, farm labour wage rates, as well as national and United States coffee stocks were used as socioeconomic variables. Applications of this model in the Caribbean, using data for Trinidad and Tobago, Saint Lucia, Guyana and Jamaica, have appeared in recent United Nations publications (ECLAC, 2011a; 2011b; 2011c; 2011d).

One advantage of the production function approach was that historical farm-level and aggregate data implicitly included farmers' adaptation to climate change by shifting production choices. However, since most of the models used only temperature and precipitation (or variants of these) as independent variables, the effects of other important climate variables were usually omitted in this approach. In addition, these models could not integrate sufficiently the expected CO2 fertilization effects on plants, due to low variations in historical CO2 concentrations (Finger and Schmid, 2007). Further, according to Deschenes and Greenstone (2006), the production function approach provided estimates of weather effects on crop yields that did not include bias due to agricultural output factors that were beyond farmers' control, such as soil quality. Further, these authors noted that production function estimates did not account for the full range of adaptation responses that farmers could make to changes in weather in order to maximize their profits. Since the production technology was fixed, this approach would be likely to overstate climate impacts.

F. Integrated assessment models

Integrated Assessment Models (IAMs) are macroeconomic models which model the linkages between aggregate outputs of various sectors of the economy, in a generalized general equilibrium model approach, which seeks to maximize total discounted outputs for a region. IAMs combine knowledge from different disciplines in order to model the impacts of production and consumption processes on climate change, and the backward effects of increased emissions on the economy and ecosystems (Patt and others, 2010). These models include the Dynamic Integrated Climate and Economy (DICE) model, and the RICE, a regional version of the DICE model, as used by Dellink, de Bruin and van Ierland (2010), Patt and others (2010), de Bruin, Dellink and Tol (2009) and Tol (1996). These models have been useful for showing countrywide impacts of changes in different sectors, which have provided valid data about proposed changes in public policies or the possible impacts of unanticipated changes, such as extreme events. Another key strength is that RICE models, unlike many of the other IAMs, have been able to include adaptation options explicitly as control variables (to form the AD-RICE model). In this way, the possible trade-offs between mitigation and adaptation options could be assessed better (Patt and others, 2010). However, the major downfall of this model approach has been that the detailed interactions within the agricultural sector (such as plant-soil relationships) could not be modelled, so that the agricultural response in this model might be truncated, or the impacts on agriculture due to changes in other sectors might not be fully shown. Furthermore, its use in application to the agricultural sector has provided only limited estimates of climate impacts, since the model considered only aggregate agricultural output. Any individual crops included have been usually a scant number of cash crops. Since different crops can have marked variations in response to climate change, the use of a few crops only to represent the agricultural sector in these models has been a constraint.

All of the abovementioned models were, theoretically, appropriate for use in modelling agricultural production in the Caribbean; however, given that household-level data on output, prices and input use were not available, the utilization of the production function approach, the Ricardian model, the fixed effects model and agroeconomic model had to be ruled out. Price data for livestock were not available generally for any prolonged time series in most of the study countries, so livestock analysis was not possible. Therefore, only the agro-ecological model, specifically, the Global Agro-ecological Zone Model (GAEZ) was considered appropriate.

V. Methodology

The present study has used the Global Agro-Ecological Zones model, GAEZ version 3.0, released on May 25, 2012 (FAO, 2012b). The agro-ecological zone methodology for determining crop potential and the health of different agricultural resources has been developed and perfected by FAO and IIASA for over 30 years. Agro-ecological zones have been defined as *homogenous areas with similar soil, land and climate characteristics.*

A. Data requirements

Information was presented at three possible input levels (low, intermediate, high) on:

a) Agro-ecological zones
b) Agro-climatically attainable yields
c) Yield constraints
d) Crop calendars
e) Agro-ecological suitability and productivity assessments
f) Potential production estimates
g) Actual yield and production
h) Yield and production gaps

Productivity estimates were made for different water supply systems:

i. rain-fed production
ii. rain-fed production with water conservation
iii. irrigated production, including a specification by irrigation type (gravity, sprinkler or drip irrigation system)

B. Crops

Analysis was available for 11 crop groups, which included 49 crops. The crop groups were: bioenergy feedstock, cereal, fibre crops, fodder crops, fruit, narcotics and stimulants (e.g. coffee, tea), oil crops, pulses, root crops and tubers, sugar crops and vegetables.

C. Baseline and other time horizons

Historical inputs for climate were based on specific years from 1961 to 2000, as well as a baseline period, which used the average climate for the 30-year horizon 1961-1990. The historical climate could then be compared to three future time periods: 2020s (2011-2040), 2050s (2041-2070) and the 2080s (2071-2100).

D. Resolution

GAEZ produced five arc-minute (0.083 degree) resolutions of global inventories of actual harvested areas, yield and production for major crops/commodities. The results were based on 0.5 degree latitude/longitude world climate datasets for individual years, and 0.17 degrees for 1961-1990 average climate, 0.5 degree soils data contained in the Harmonized World Soil Database (HWSD), 0.5 degree Global Land Cover Characteristics Database, and a 0.05 degree Shuttle Radar Topography Mission (SRTM) digital elevation dataset.

E. Input/management level

The three generic levels of input/management were defined as:

a) **Low level inputs**. This assumed a subsistence-type farming system. Production was assumed to be based on the use of traditional cultivars. Should improved cultivars be used, they would be expected to be managed in the same way as traditional cultivars. The farming system was characterized by labour-intensive techniques, no fertilizer application, and limited conservation measures.

b) **Intermediate level inputs**. This approach was assumed to be partly market-oriented and partly subsistence. Improved varieties were used with manual labour and the use of hand tools, so the system was medium labour-intensive. There was some mechanization, some fertilizer and pesticide application, some weed control, adequate fallows and some conservation measures.

c) **High level inputs**. This farming system was assumed to be largely market-oriented, with the use of improved, high-yielding varieties. The system was assumed to be fully mechanized with low labour-intensity. It used optimum fertilizer application, optimum pesticide application and optimum weed control.

F. Climate scenarios

Four General Circulation Models (GCMs) were used in GAEZ to estimate future agricultural productivity:

i. HadCM3 (Hadley Centre, United Kingdom Meteorological Office)

ii. ECHAM4 (European Centre Hamburg global climate model, Max-Planck-Institute for Meteorology, Germany)

iii. CSIRO (Commonwealth Scientific and Industrial Research Organization, Australia)

iv. CGCM2 (Canadian General Circulation Model)

G. Carbon dioxide fertilization

Analysis could be done with, or without, the possible effects of CO2 fertilization. In general, it was expected that plants would grow bigger and more rapidly in the presence of increased CO2. The key agricultural plants are C3 plants (about 85 per cent) followed by C4 plants. C3 plants include wheat, rice, soybean and most broadleaf plants, and fix CO2 directly (Gowik and Westhoff, 2011; Biology Online, 2013a). They are better-suited than C4 plants to environments with high CO2 concentrations, moderate light and temperature, and abundant water supplies, and are expected to have the highest increase in productivity as a result of increased CO2 concentrations (UNEP, 1990). C4 plants, which include maize and sugarcane, fix CO2 in a two-step procedure, are better adapted to drier and hotter areas with limited CO2, and are not expected to respond as dramatically to increases in atmospheric CO2 concentrations, as the C3 plants (UNEP, 1990; Biology Online, 2013b).

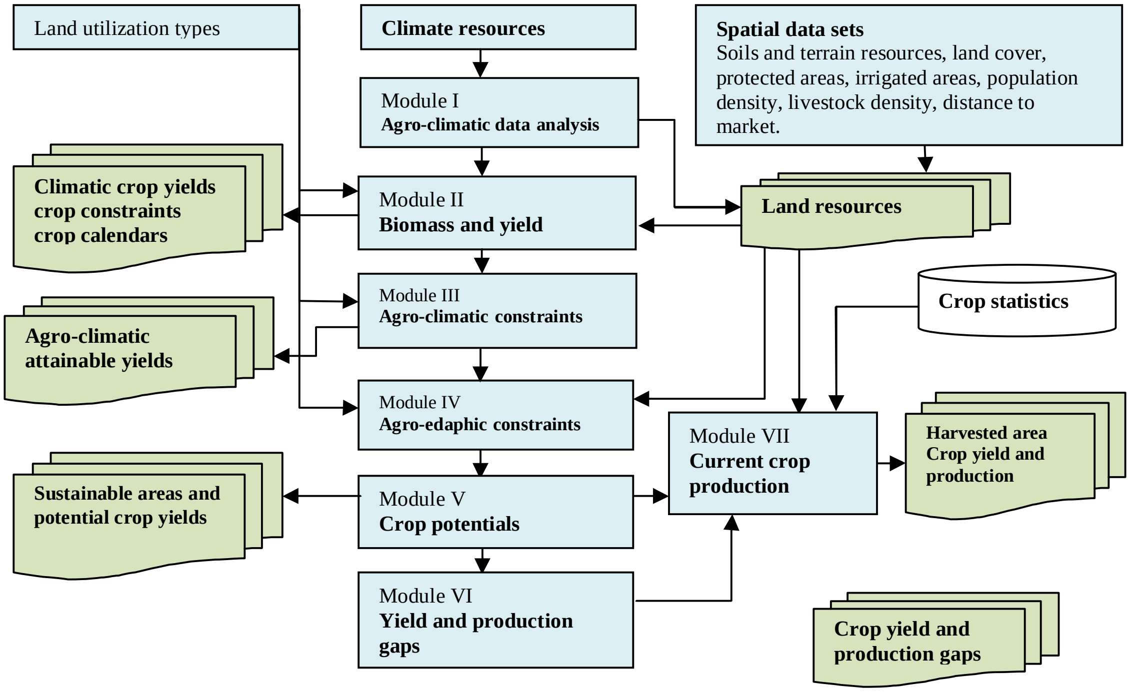
Integration of all the model elements is shown in figure 12. The land utilization types were a set of technical specifications of crop production within a given socioeconomic setting. Each land utilization type specified agronomic information, nature of main produce, water-supply type, cultivation practices, and utilization of crop residues and by-products.

H. Crop and scenario selection

Based on the quantity of crop production by individual crops, the top seven crops were selected for analysis. These were: sugarcane (irrigated and rain-fed), rice, banana (and plantain), cassava, yam, sweet potato, and tomato.

The Hadley general circulation model was used in estimating the future scenarios, as the temperature and rainfall projections under the Hadley scenario were the closest match to the projections under the PRECIS (Providing Regional Climates for Impact Studies) Caribbean model, a downscaled regional model considered to provide the best climate projections for the Caribbean. Estimates of the crop production system used in the model were based on the most commonly-prevailing systems in the Caribbean. Both irrigated and rain-fed production was modelled for sugarcane. It was assumed that an intermediate level of input was used. The type of rice used was the wetland rice under irrigated systems with an intermediate level of input. Rain-fed systems were assumed for root crops under both low and intermediate levels of input. The rain-fed system was modelled for tomato, with an intermediate level of input, as the intermediate level of input should be used whenever the production system is partially market-oriented, which is the case for most of the production of non-export crops.

FIGURE 12
GENERAL STRUCTURE AND DATA INTEGRATION OF GLOBAL AGRO-ECOLOGICAL ZONES MODEL, VERSION 3.0



Source: Food and Agriculture Organization of the United Nations (FAO), "GAEZ ver 3.0: Global Agro-ecological Zones Model Documentation" [online], [date of reference: August 2012], <http://www.fao.org/fileadmin/user_upload /gaez/docs/GAEZ_Model_Documentation.pdf>

VI. Data

Annual time series data from 1961 to 2010 on crop production for all crops were obtained from FAOSTAT, the FAO online statistical database. In some cases, these data were based on actual country data. In other cases, the data were FAO estimates based on past production. Data on crop prices were only available for a few countries from the FAOSTAT database and largely unavailable from countries for significant time periods, or for a significant range of crops. Data on livestock production and livestock prices were neither available on a consistent basis, nor for sufficiently long time series, across countries, nor for a wide range of livestock products. This crop production data from FAOSTAT was used in the GAEZ model.

Data on inflation of general consumer prices were obtained from FAOSTAT (for Cuba, Suriname and Trinidad and Tobago), the Eastern Caribbean Central Bank (for Saint Kitts and Nevis, Saint Lucia, and Saint Vincent and the Grenadines) and the World Bank online databank (for all other countries).

Other data on topography, land classification, soil type, and water balance were embedded in the GAEZ model (FAO, 2012c). Information on databases was obtained from FAO (2012c).

A. Databases

1. Observed climate

Time-series data used were taken from the Climate Research Unit (CRU) at the University of East Anglia, 10 arc-minute latitude/longitude gridded average monthly climate data, version CRU CL 2.0, and 30 arc-minute latitude/longitude gridded monthly climate data time series for the period 1901-2002, version CRU TS 2.1. These climate data formed the basis for demarcating agro-ecological zones.

2. Climate scenarios

Twelve GCM-climate IPCC_AR4 scenario combinations were used for the 2020s, 2050s and 2080s. Original monthly Climate Research Unit (CRU) at the University of East Anglia CRU 10 arc-minute and Global Precipitation Climatology Centre (GPCC) and CRU 30 arc-minute latitude/longitude climatic surfaces were interpolated at IIASA to a 5 arc-minute grid for all years between 1960 and 2002. Monthly climatic variables used included precipitation, number of rainy days, mean minimum and mean maximum temperature, diurnal temperature range, cloudiness, wind speed (only the average for 1961-1990 were available from CRU CL 2.0), and vapor pressure.

3. Soils

Soil data were derived from the Land Use Change and Agriculture Programme of IIASA (LUC) and the Food and Agriculture Organization of the United Nations (FAO) comprehensive Harmonized World Soil Database (HWSD). HWSD is a 30 arc-second raster database with over 16 000 different soil mapping units, that combines existing regional and national updates of soil information worldwide (SOTER, ESD, Soil Map of China, WISE) with the information contained within the 1:5 000 000 scale FAO-UNESCO Soil Map of the World.

4. Terrain

Elevation data and derived slope and aspect data derived from Shuttle Radar Topography Mission (SRTM)

5. Irrigated areas

Data on irrigated areas were derived from Digital Global Map of Irrigated Areas (GMIA) version 4.01

6. Land cover and population density data

Six geographical datasets were used for the compilation of an inventory of seven major land cover/land use categories at a 5 arc-minute resolution. The datasets used were:

a) GLC2000 land cover, regional and global classifications at 30 arc-seconds

b) The International Food Policy Research Institute (IFPRI) Agricultural Extent database, which is a global land cover categorization providing 17 land cover classes at 30 arc-seconds, based on a reinterpretation of the Global Land Cover Characteristics Database, EROS Data Centre

c) The Global Forest Resources Assessment 2000 and 2005 of FAO at 30 arc-seconds resolution

d) Digital Global Map of Irrigated Areas (GMIA) version 4.01 at 5 arc-minute latitude/longitude resolution, providing by grid-cell the percentage land area equipped with irrigation infrastructure

e) The joint International Union for Conservation of Nature (IUCN)-World Conservation Monitoring Centre (WCMC) protected areas inventory at 30-arc-seconds

f) Spatial population density inventory (30 arc-seconds) for year 2000 developed by the FAO Environment and Natural Resources Service (FAO-SDRN), based on spatial data of LANDSCAN 2003, LandScanTM Global Population Database, with calibration to United Nations 2000 population figures.

7. Protected areas

Data on protected areas were derived from the World Database on Protected Areas Annual Release, 2009.

8. Administrative areas

Data on administrative areas were derived from the Global Administrative Unit Layers (GAUL) of 2009.

B. Statistical data

Statistical data were derived from the following sources:

i. FAO Forest Resources Assessments (FRA 2000, FRA 2005, FRA 2010)

ii. FAOSTAT

iii. AQUASTAT

iv. United Nations Population Statistics

Yield- and production gaps have been estimated by comparing potential attainable yields and production (using low- and mixed- input levels) with actual achieved yields and production (years 2000 and 2005).

VII. Results

Throughout the rest of the twenty-first century, temperatures in the Caribbean have been forecast to rise slowly and steadily (table 7). By the 2050s, (2041-2070) the mean temperature was expected to rise by 1.54° C under the B2 scenario, and by 1.79° C under the A2 scenario. This forecast has been based on the Hadley global climate model.[7] During the baseline period, the Dominican Republic was the coolest country, with an average temperature of 24.1° C; however, by the 2050s, Dominica was expected to have the coolest temperatures under either the A2 or B2 scenario.

TABLE 7
HISTORICAL AND PROJECTED (HADLEY) TEMPERATURES FOR THE CARIBBEAN. 2020s, 2050s AND 2080s
(Degrees Celsius)

		Temperature (Degrees Celsius)			
		Average	Minimum	Maximum	Range
		Historical			
		25.39	22.16	26.94	4.78
	Scenario	Forecast			
2020s	A2	26.24	23.01	27.83	4.82
	B2	26.32	23.09	27.91	4.82
2050s	A2	27.2	24.0	28.8	4.9
	B2	26.93	23.69	28.53	4.84
2080s	A2	28.4	25.1	30.1	5.0
	B2	27.66	24.43	29.32	4.89

Source: Data compiled by author

7 Hadley average annual temperature projections by Caribbean country by decade are shown in annex 4.

Similarly, it was forecast that total annual rainfall would decline under both the A2 and B2 scenarios, with a more dramatic fall under A2. Under the B2 scenario and by the 2050s (2041-2070) rainfall was expected to fall by more than 20 per cent (table 8).

TABLE 8
HISTORICAL AND PROJECTED (HADLEY) RAINFALL FOR THE CARIBBEAN UNDER A2 AND B2 CLIMATE SCENARIOS, 2011-2100
(Millimetres)

		Sum	Minimum	Maximum	Range
	Historical	24 470	20 517	27 987	7 470
2020s	A2	20 847	17 211	24 193	6 982
	B2	21 377	17 715	24 750	7 035
2050s	A2	17 228	14 020	20 211	6 191
	B2	20 506	16 964	23 772	6 808
2080s	A2	12 604	9 860	15 225	5 365
	B2	14 922	11 918	17 817	5 899

Source: Data compiled by author.

Hadley weighted, annual rainfall projections, by country, are shown in annex 5. During the base period, Dominica had the most rainfall at 2,229 mm. however, by the 2050s Belize was expected to have the highest annual rainfall under either the A2 or B2 scenario

A. Potential production capacity on currently cultivated land in the Caribbean

One of the key outcomes of the modelling exercise has been the determination of changes in the potential yields of the key crops. This has been shown, successively, from tables 9 to 14. The weighted, average, potential yield of cassava on currently cultivated land in the Caribbean has been forecast to be 2.12 tonnes per hectare (t/ha.). Under both the A2 and B2 scenarios, this potential yield varied over time from the 2020s to the 2050s. Under the A2 scenario, the potential yield fell by 22 per cent in the 2050s. However, in the B2 scenario, the potential yield initially rose slightly in response to drier, warmer conditions, but declined thereafter, as the temperature continued to rise and rainfall to decline further.

TABLE 9
POTENTIAL PRODUCTION CAPACITY FOR CASSAVA, BY CARIBBEAN COUNTRY UNDER A2 AND B2 CLIMATE SCENARIOS
(Tonnes per hectare)

Country	Cassava			Potential production with CO_2 (t/ha.)			
				2020s		2050s	
	Harvested area (2000-Km^2)	Harvested area (ha.)	Potentialproduction base (t/ha.)	A2	B2	A2	B2
Antigua and Barbuda	0.32	32	1.78	1.83	1.81	1.75	1.80
The Bahamas	0.17	17	0.28	0.28	0.28	0.28	0.29
Barbados			2.49	2.56	2.53	2.65	2.59
Belize	8.2576986	826	1.40	1.59	1.49	1.78	1.55
Cuba	1 827.56	182 756	1.65	1.65	1.67	1.55	1.65
Dominica		97	1.81	2.22	2.21	2.81	2.25
The Dominican Republic	490.96894	49 097	2.55	2.55	2.56	2.20	2.55
Grenada		28	3.49	3.60	3.56	3.73	3.63
Guyana	96.919457	9 692	2.14	2.19	2.21	1.81	1.98
Haiti	1 754.3581	175 436	2.59	2.56	2.58	1.69	2.56
Jamaica	141.63	14 163	1.18	0.99	1.02	0.51	0.95
Saint Kitts and Nevis		0	2.34	2.36	2.33	2.24	2.36
Saint Lucia		320	2.42	2.56	2.51	2.51	2.50
Saint Vincent and the Grenadines		40					
Suriname	11.991796	1 199	1.42	1.63	1.64	1.46	1.52
Trinidad and Tobago		65	1.14	1.24	1.23	1.23	1.20
Caribbean	4 332.176	433 768	2.12	2.11	2.13	1.65	2.10
	Total	Total	Ave.*	Ave.*	Ave.*	Ave.*	Ave.*

Source: Data compiled by author

Note: * Weighted Average

The potential yield for tomato fell by approximately 28 per cent under the A2 scenario by the 2050s, and by approximately 17 per cent under the B2 scenario (table 10).

TABLE 10
POTENTIAL PRODUCTION CAPACITY FOR RAIN-FED TOMATO, BY CARIBBEAN COUNTRY UNDER A2 AND B2 CLIMATE SCENARIOS, 2020s AND 2050s

Tomatoes - rain-fed				2020s		2050s	
Country	Harvested area in 2000 (Km^2)	Harvested area (ha.)	Potential production base (t/ha.)	A2	B2	A2	B2
Antigua and Barbuda		30	2.01	1.71	1.64	1.49	1.61
The Bahamas		372	1.53	1.38	1.49	1.22	1.31
Barbados		55	3.27	3.06	3.04	2.78	2.89
Belize		100	1.35	1.48	1.34	1.47	1.35
Cuba		42 585	1.91	1.73	1.75	1.40	1.56
Dominica		24	1.80	1.92	1.87	3.02	2.03
The Dominican Republic		10 279	2.83	2.66	2.65	1.95	2.45
Grenada		12	3.52	3.32	3.31	2.24	3.10
Guyana		780	1.71	1.81	1.80	1.34	1.53
Haiti		390	2.62	2.23	2.21	1.32	1.97
Jamaica		1 193	1.14	0.91	0.91	0.56	0.76
Saint Kitts and Nevis		0	3.35	2.84	2.80	2.24	2.58
Saint Lucia		0	1.93	2.17	2.15	1.94	1.91
Saint Vincent and the Grenadines		0					
Suriname		77	1.14	1.32	1.36	0.95	1.17
Trinidad and Tobago		220	0.91	0.97	0.97	0.80	0.84
Caribbean	0	56 117	2.04	1.87	1.89	1.47	1.70
	Total	Total	Weighted average	Weighted average	Weighted average	Weighted average	Weighted average

Source: Data compiled by author

The potential yield of irrigated sugarcane fell consistently under both the A2 and B2 scenarios, relative to the yield in the year 2000.[8] Potential yield for currently cultivated land fell marginally by 0.9 per cent under the A2 scenario by the 2050s, and by approximately 0. 7 per cent under the B2 scenario (tables 11 and 12). Declines in yield were similar for rain-fed sugarcane.

The potential yield of rice showed a different pattern to the other crops. Under the A2 scenario, the potential yield fell by approximately 3 per cent by the 2050s. However, in the B2 scenario, the potential yield rose by approximately 2 per cent over the same period. Overall, for all crops, potential output was expected to fall by approximately 12 per cent under the A2 scenario by the 2050s. Over the same time period, yield was projected to fall by 7 per cent under the B2 scenario.

8 The year 2000 was used, since this was the reference year used in the GAEZ model for which actual production, yield, area harvested and the associated crop values were available.

TABLE 11
CARIBBEAN POTENTIAL PRODUCTION CAPACITY FOR IRRIGATED SUGARCANE

				Yield (t/ha-)			
		Current climate		2020s		2050s	
Crop	Area (ha.)	Production (tons)	Yield (t/ha)	A2	B2	A2	B2
Sugarcane - irrigated	617 638.0	3 572 341.0	5.78	5.69	5.70	5.26	5.35
Sugarcane - rain-fed	690 513.3	2 686 099.4	3.89	3.45	3.73	3.18	3.41
All sugarcane	1 308 151.3	6 258 440.4	4.78	4.50	4.66	4.16	4.32
Rice	690 513.3	1 576 425.5	3.89	3.73	3.94	3.78	3.97
Bananas/plantains	309 514.0	509 546.2	1.65	1.34	1.45	1.11	1.32
Cassava	433 767.6	921 734.3	2.12	2.11	2.13	1.65	2.10
Yams	71 719.5	82 235.6	1.15	1.13	1.14	0.98	1.07
Sweet potato	134 455.9	313 852.9	2.33	2.23	2.25	1.79	2.17
Tomato	56 117.0	114 705.7	2.04	1.87	1.89	1.47	1.70
All crops	3 004 238.6	9 776 940.4	4.20	4.00	4.12	3.70	3.89

Source: Data compiled by author

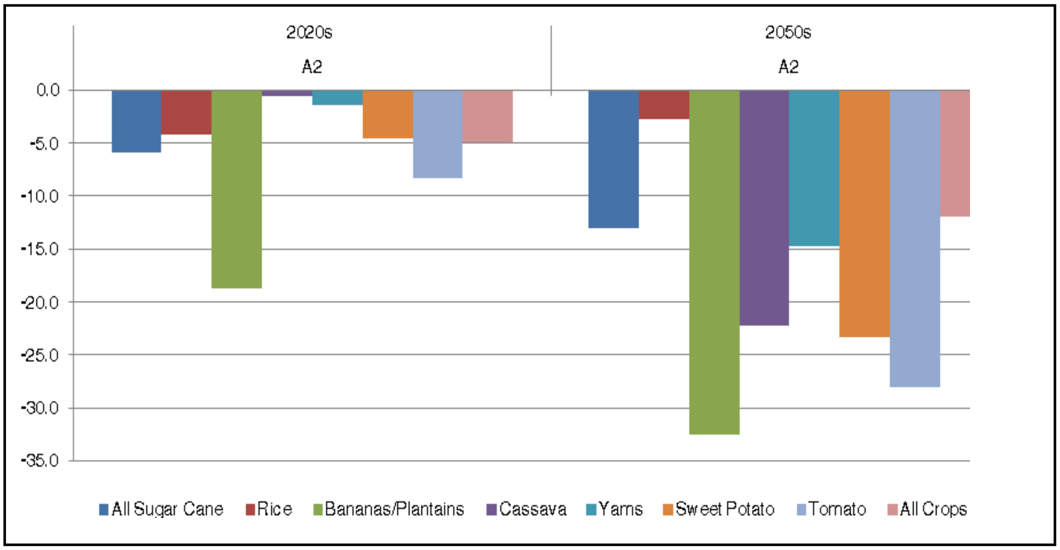
Out of all the crops considered, bananas and plantains were expected to have the largest decline in potential yield, by approximately 33 per cent under the A2 scenario, which was considered the Business as Usual case. When compared to B2, the fall in yield was still large, at almost 20 per cent. Rice was expected to have the best outcome, largely due to the CO2 fertilization effect of this C3 plant, versus the other crops, which were C4 plants. The percentage change in potential production is shown in figure 12. The potential production capacity on currently cultivated land for irrigated sugarcane and rice are shown in annex 6.

TABLE 12
PERCENTAGE CHANGE IN POTENTIAL CROP YIELD IN THE CARIBBEAN UNDER A2 AND B2 CLIMATE SCENARIOS, 2020S AND 2050S
(Percentage)

	2020s		2050s	
Crop	A2	B2	A2	B2
	Percentage change			
Sugarcane - irrigated	-1.7	-1.4	-9.1	-7.6
Sugarcane - rain-fed	-11.4	-4.2	-18.2	-12.4
All Sugarcane	-5.9	-2.6	-13.0	-9.6
Rice	-4.2	1.3	-2.8	2.0
Bananas/plantains	-18.8	-12.0	-32.5	-19.9
Cassava	-0.6	0.1	-22.2	-1.2
Yams	-1.5	-1.0	-14.7	-6.3
Sweet potato	-4.6	-3.8	-23.4	-6.9
Tomato	-8.3	-7.6	-28.1	-16.9
All crops	-4.9	-1.9	-11.9	-7.4

Source: Data compiled by author

FIGURE 13
CHANGE IN POTENTIAL CARIBBEAN AGRICULTURAL PRODUCTION UNDER THE A2 SCENARIO, 2020S AND 2050S
(Percentage)



Source: Prepared by Author

When all the changes in potential production were aggregated over all crops, the value of production in 2000 was compared to the estimated value of production under the new yield outcomes, with the assumption that the same 2000 prices prevailed in the 2020s and 2050s. The average annual change in income is shown in table 13.

TABLE 13
AVERAGE ANNUAL INCOME CHANGE IN THE VALUE OF CROP YIELDS IN THE CARIBBEAN UNDER A2 AND B2 CLIMATE SCENARIOS, 2020s AND 2050s
(United States dollars)

Crop	Current climate	2020s		2050s	
		A2	B2	A2	B2
	Value	Average annual income change			
Sugarcane - irrigated	93 345 271	-1 587 379	-1 337 573	-8 468 701	-7 081 764
Sugarcane - rain-fed	70 187 777	-8 021 649	-2 914 214	-12 779 824	-8 670 795
All sugarcane	163 533 047	-9 609 028	-4 251 788	-21 248 524	-15 752 560
Rice	333 729 276	-14 004 688	4 394 328	-9 184 114	6 673 660
Bananas/plantains	215 395 352	-40 406 605	-25 826 683	-70 013 723	-42 935 326
Cassava	356 213 429	-2 116 741	522 237	-79 165 778	-4 131 366
Yams	65 538 460	-958 643	-637 037	-9 641 209	-4 159 699
Sweet potato	203 821 275	-9 392 019	-7 658 826	-47 603 500	-14 095 758
Tomato	124 264 489	-10 307 951	-9 417 022	-34 881 424	-21 056 151
All crops	1 462 495 328.6	-86 795 676	-42 874 790	-271 738 272	-95 457 199

Source: Data compiled by author

For all crops combined, it was estimated that there would be an annual loss of income (based on producer prices) of US$ 86.7 million under the A2 scenario in the 2020s, which would worsen to an annual loss of US $ 271.7 million by the 2050s. Under the B2 scenario, income losses were much smaller by the 2050s.

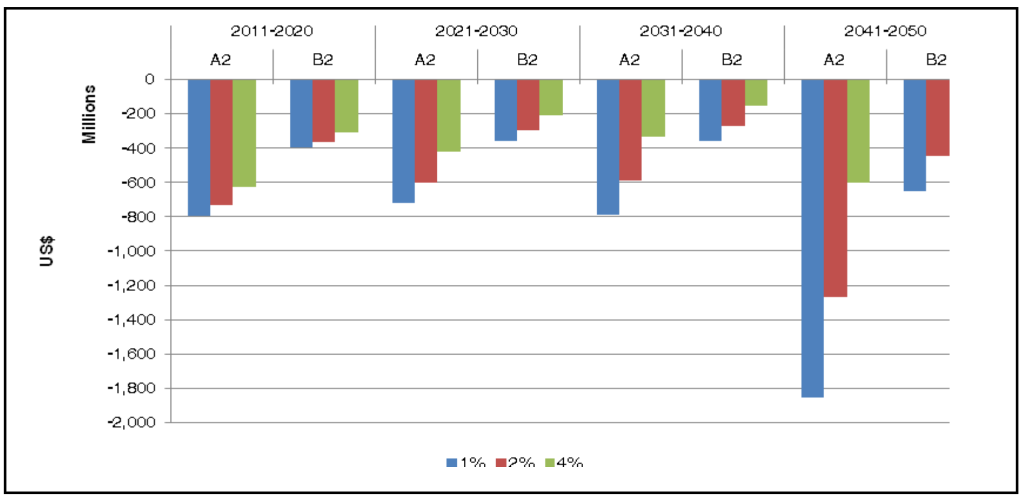
The net present value of the annual income losses are shown, by decade, in table 14, using discount rates of 1 per cent, 2 per cent and 4 per cent. As the discount rate increases, equivalent losses obtained at the same time in the future, will have a smaller present value. The 1 per cent discount rate provided a case where the future values of benefits and costs have a higher value relative to present values of benefits and costs, and is the preferred discount rate if society places a higher value on environmental impacts. Overall, losses under the A2 scenario approximately triple the losses projected under the B2 scenario in the period 2041-2050. These losses are shown in figure 14.

TABLE 14
NET PRESENT VALUE OF CUMULATIVE LOSS IN VALUE OF CROP YIELDS IN THE CARIBBEAN UNDER A2 AND B2 CLIMATE SCENARIOS, 2011-2050
(Millions of United States dollars)

Discount rate	2011-2020		2021-2030		2031-2040		2041-2050	
	A2	B2	A2	B2	A2	B2	A2	B2
1 per cent	-797.9	-394.1	-722.3	-356.8	-787.1	-360.9	-1,853.3	-651.0
2 per cent	-734.7	-362.9	-602.7	-297.7	-590.6	-271.6	-1,269.8	-446.1
4 per cent	-625.8	-309.2	-422.8	-208.9	-336.3	-155.5	-604.1	-212.2

Source: Data compiled by author

FIGURE 14
NET PRESENT VALUE OF CUMULATIVE CARIBBEAN AGRICULTURAL SECTOR LOSSES UNDER A2 AND B2, 2011-2050
(Millions of United States dollars)



Source: Prepared by Author

The net present value of the forecast cumulative income changes for the Caribbean agricultural sector under A2 and B2, based on 2007 United States dollars, are shown in table 15. Relative to A2, agricultural sector losses declined slightly to moderately under the B2 scenario between 2011-2020 and 2031-2040, but showed a sharp increase in the 2040s (figure 15) For example, at the 1 per cent discount rate, losses were US$404 million lower under the B2 scenario, relative to A2 during 2011-2020. By 2021-2030, losses under B2 (relative to A2) fell by 9 per cent to US$ 366 million, and rose by 16 per cent to US$ 426 million by 2031-2040. However, between 2031-

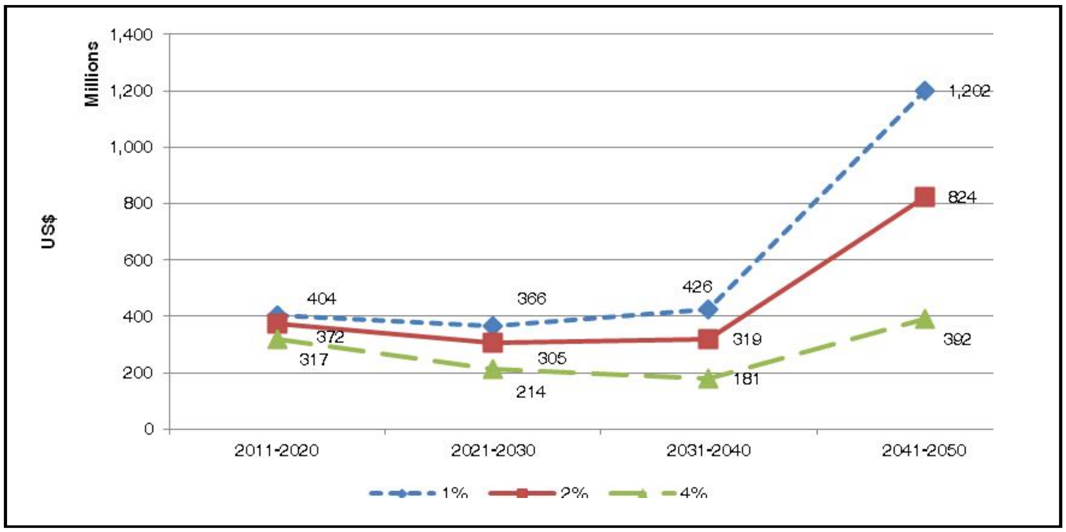
2040 and 2041-2050, losses under B2 relative to A2 rose by 182 per cent to reach US$1,202 million. This highlighted the fact that losses under A2 and B2 widened, as one moves further into the future, with A2 having the worse impacts of the two scenarios.

TABLE 15
NET PRESENT VALUE OF CUMULATIVE CARIBBEAN AGRICULTURAL SECTOR INCOME CHANGES UNDER A2 AND B2 CLIMATE SCENARIOS, 2011-2050
(2007 United States dollars)

	A2	B2
1 per cent	-4 244 880 995	-1 804 484 877
2 per cent	-3 279 629 558	-1 418 686 854
4 per cent	-2 066 238 739	-923 838 713

Source: Data compiled by author

FIGURE 15
NET PRESENT VALUE OF CARIBBEAN AGRICULTURAL SECTOR INCOME CHANGES UNDER B2 RELATIVE TO A2, DISCOUNTED AT 1%, 2% AND 4%, 2011-2050
(Millions of United States dollars)



Source: Prepared by Author

B. Crop suitability by class on currently cultivated land

In considering the current area of arable land that was assessed by the model under the Hadley scenario, there were significant changes observed in the proportion of land with high, or very high, suitability for rain-fed cassava production, using intermediate inputs, relative to the baseline period (1961-1990) (table 16). Under the A2 scenario, significantly more land was deemed unsuitable by the 2050s, relative to the B2 climate scenario.

TABLE 16
CHANGES IN LAND SUITABILITY FOR CASSAVA PRODUCTION IN THE CARIBBEAN UNDER A2 AND B2 CLIMATE SCENARIOS, 2020s TO 2050s
(Square kilometres)

		2020s		2050s	
	Baseline	A2	B2	A2	B2
SI = 0 : Not suitable	5 187	3 669	3 424	16 148	2 599
SI > 0 : Very marginal	0	0	0	0	0
SI > 10 : Marginal	63 143	67 527	65 885	87 355	70 596
SI > 25 : Moderate	67 654	65 366	65 389	81 744	75 715
SI > 40 : Medium	11 775	11 461	11 431	11 249	11 171
SI > 55 : Good	56 678	78 570	72 309	91 766	96 240
SI > 70 : High	95 502	76 585	81 768	21 063	46 429
SI > 85 : Very high	32 653	29 414	32 386	23 267	29 840

Source: Data compiled by Author

Note : SI = Suitability Index

There were significant changes in the proportion of land assessed by the model with high or very high suitability for irrigated sugarcane production using intermediate inputs, relative to the baseline period (1961-1990) (table 17). Under the A2 scenario, more than 70 per cent of the land that had been deemed as having very high suitability for irrigated sugarcane production under the baseline was no longer classified as suitable whereas, under the B2 scenario, approximately 50 per cent of land classified as suitable for irrigated sugarcane production was lost.

TABLE 17
CHANGES IN LAND SUITABILITY FOR IRRIGATED SUGARCANE PRODUCTION IN THE CARIBEAN UNDER A2 AND B2 CLIMATE SCENARIOS, 2020s AND 2050s
(Square kilometres)

		2020s		2050s	
	Base	A2	B2	A2	B2
SI = 0 : Not suitable	1 920	1 389	1 307	1 109	1 301
SI > 0 : Very marginal	0	0	0	0	0
SI > 10 : Marginal	15 189	15 510	15 510	15 960	15 590
SI > 25 : Moderate	9 961	13 589	13 776	23 382	19 657
SI > 40 : Medium	3 014	2 797	2 477	2 033	2 682
SI > 55 : Good	39 171	40 289	39 357	45 526	44 817
SI > 70 : High	38 828	41 187	38 855	29 793	30 814
SI > 85 : Very high	14 249	7 572	11 049	4 528	7 470

Source: Data compiled by Author

A large proportion of all the land assessed by the model, currently under cultivation for rain-fed sugarcane production using intermediate inputs, became unsuitable for sugarcane production under the A2 scenario, relative to the baseline period (1961-1990) (table 18). As with irrigated sugarcane, land, in general became more unsuitable for rain-fed sugarcane production over time.

TABLE 18
CHANGES IN LAND SUITABILITY FOR RAIN-FED SUGARCANE PRODUCTION IN THE CARIBBEAN UNDER A2 AND B2 CLIMATE SCENARIOS, 2020s AND 2050s
(Square kilometres)

		2020s		2050s	
	Baseline	A2	B2	A2	B2
SI = 0 : Not suitable	5 576	17 501	11 765	76 910	21 333
SI > 0 : Very marginal	0	0	0	0	0
SI > 10 : Marginal	47 301	57 980	48 687	89 767	60 808
SI > 25 : Moderate	49 422	115 493	101 333	100 232	137 207
SI > 40 : Medium	24 731	16 992	20 887	8 804	14 611
SI > 55 : Good	132 462	87 378	99 481	39 624	66 833
SI > 70 : High	55 638	26 353	31 240	10 722	18 345
SI > 85 : Very high	17 461	10 895	19 199	6 533	13 454

Source: Data compiled by Author

There were very similar profiles for land suitability of the land that was assessed by the model for irrigated rice production, using intermediate inputs, under the B2 scenario from the 2020s to the 2050s. However, under the A2 scenario, there were major changes, especially in the proportion of land deemed unsuitable for rice production (table 19).

TABLE 19
CHANGES IN LAND SUITABILITY FOR IRRIGATED RICE PRODUCTION IN THE CARIBBEAN UNDER A2 AND B2 CLIMATE SCENARIOS, 2020s AND 2050s
(Square kilometres)

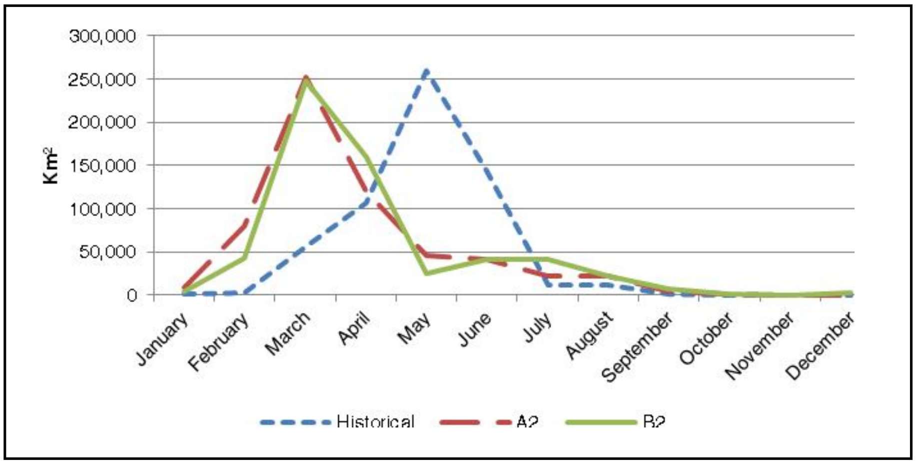
YEAR		2020s		2050s	
CLIMATE SCENARIO	Baseline	A2	B2	A2	B2
SI = 0 : Not suitable	1 912	66 729	1 307	66 160	1 057
SI > 0 : Very marginal	0	0	0	0	0
SI > 10 : Marginal	5 707	846	6 325	846	6 331
SI > 25 : Moderate	23 724	7 373	24 152	7 903	24 885
SI > 40 : Medium	7 402	3 710	8 342	3 872	7 899
SI > 55 : Good	31 989	21 408	30 939	21 368	31 732
SI > 70 : High	49 230	20 994	49 360	20 912	49 003
SI > 85 : Very high	2 368	1 270	1 907	1 270	1 425

Source: Data compiled by Author

C. Start of the Caribbean crop cycle – sweet potato to the 2020s

Only rain-fed scenarios were available in the GAEZ model to assess potential changes in the start date of crop cycles. The model used the start date that would match optimally the climatic conditions in each grid cell to the crop requirements for the entire crop cycle. Using the illustration of sweet potato (figure 16), rain-fed potato production using limited inputs was expected to shift in the Caribbean from May to March. However, such an adjustment would depend on whether farmers maintained existing crops or switched to new crops. That decision would be country- and region- specific, depending on the adaptive capacity of the producers.

FIGURE 16
AREA AND MONTHS IN WHICH THE CARIBBEAN SWEET POTATO CROP PRODUCTION CYCLE STARTS UNDER A2 AND B2, TO 2020S
(Square Kilometers)



Source: Author's calculations

D. Potential impacts of sea-level rise

The estimated sea-level rise was 3.1 mm/year, based on IPCC projections for the global mean (Simpson and others, 2009). Over the 40-year period from 2011 to 2050, therefore, the sea level was expected to rise by 124 mm, or 0.124 metres. The projected SLR for Trinidad and Tobago (also assumed for Suriname) would be greater at 4.2 mm/year. Simpson and others (2009) indicated that the crop (and plantation) land represented cultivated land. The crop values represented the annual value of all crops produced in each country, based on FAO data. Given the projected percentage loss of crop land in 2050 and annual crop values for 2010, estimates of projected impacts as a result of the expected rise in sea level have been provided in table 20.

The impacts of sea-level rise on the Caribbean agricultural sector have been based primarily on the coastal topography of Caribbean countries, the location of cultivated land, and the potential for saltwater intrusion – which significantly reduces soil quality, inundation from high tide levels, and storm surges. The expected loss of crop land, as reported, was based on land lost due to inundation. Several countries have steep coastal gradients. These include Dominica, Grenada, Saint Kitts and Nevis, Saint Lucia, and Saint Vincent. Given the assumption that crop values that existed in 2010 have remained unchanged, the Bahamas and Jamaica were expected to lose US$ 0.10 million and US$ 3.86 million, respectively, in the year 2050. The net present value (in 2007 dollars) of the cumulative losses to the Caribbean agricultural sector due to sea-level rise from 2011 to 2050 were US$ 1.19 million, and US$ 44.54 million, for the Bahamas and Jamaica, respectively. This was due to the fact that the Bahamas has a coastal plain which was less than 10 m above sea level, and has low-lying islands, which are vulnerable to SLR. Jamaica has a similar coastal plain, but only in localized areas (Simpson and others, 2009). Other countries, such as Barbados, Guyana, Suriname, Belize and Haiti, also have coastal plains less than 10 m above sea level and/or low-lying island territory, but most of these coast plains are urban centres with limited agricultural activity. The extent of their vulnerability to potential saltwater intrusion was uncertain, due to data limitations.

TABLE 20
ESTIMATED IMPACTS OF SEA-LEVEL RISE ON CROP PRODUCTION IN THE CARIBBEAN IN 2050
(Millions of United States dollars)

	Estimated impacts on agricultural land from a 1m rise in sea level (per cent)	Estimated impacts on crop and plantation land from a 1m rise in sea level (per cent)	Total value of crops produced in 2010* (millions of US$)	Impact of sea-level rise in 2050 (millions of US$)
Antigua and Barbuda	1	0	8.0	0
The Bahamas	3	2	41.5	0.1
Barbados	0	0	50.0	0
Belize	1	0	134.0	0
Cuba	-	.	624.3	-
Dominica	0	0	-	-
The Dominican Republic	-	-	1 463.5	-
Grenada	0	0	2.8	0
Guyana	1	0	40.2	0
Haiti	0	0	-	-
Jamaica	2	2	1 558.0	3.9
Saint Kitts and Nevis	0	0	3.5	0
Saint Lucia	0	0	0.0	0
Saint Vincent and the Grenadines	0	0	10.4	0
Suriname	4	0	154.0	0
Trinidad and Tobago	0	0	173.0	0

Source: Data compiled by Author

*Notes: Crop values, in current dollars, are for 2010 except for Bahamas (2008), Grenada (2006) and Saint Lucia (2009).

The values of impacts presented above relate to the value of permanent direct loss of agricultural land, based on limited available data. For countries such as Guyana, whose coastline is below sea level, a rising sea level rise is expected to have a significant impact on agriculture in other ways. For example, after high-rainfall events, a higher sea level would lead to lower run-off rates of water from inundated agricultural land, which may negatively affect crop growth. Further, in the event of storm surges the negative impacts of a higher sea level will be further exacerbated. However, these are high-uncertainty events with varying potential impacts (Simpson and others (2009) for an elaboration). For Guyana especially, salt water intrusion is also expected to be a significant threat, based on anecdotal evidence. This is so as the large river system is expected to take salt water further inland to agricultural areas.

VIII. Caribbean adaptation options and benefit cost analyses

Given the generally hotter, and drier, climate that is expected for the Caribbean in the coming decades, should there be a Business as Usual (A2) scenario, or even if there is a reduction of greenhouse gas emissions, as under the B2 scenario, the Caribbean will need to implement mitigation and adaptation strategies. The mitigation strategies would lead to the reduction of greenhouse gas emissions, and a reduction in the Caribbean contribution to climate change. The adaptation strategies would allow the Caribbean to cope better with and, in some cases, possibly reap benefits from, the process of climate change.

A. Implementation plan for adaptation options

The Caribbean Community Climate Change Centre (CCCCC) was mandated by Caribbean Community (CARICOM) Heads of State to develop an "Implementation plan for a framework which seeks to achieve resilient development to climate change".[9] This Plan, which was released in 2011, discussed key priorities which needed to be implemented over the short- and medium term.

1. Caribbean Community implementation plan

The following actions were identified for the Caribbean Community agricultural sector (under the listed objectives and outcomes):

a) Objective

Limit the effects of climate change on agriculture and food security

[9] Caribbean Community Climate Change Centre (CCCCC), *Delivering transformational change 2011-21: Implementing the CARICOM* '*Regional Framework for Achieving Development Resilient to Climate Change*', Belize City, Belize, 2011.

b) Outcomes

- Enhanced food security through adequate food supplies being produced to meet Caribbean food and nutrition needs by 2021
- Enhanced, and secure, livelihoods in the agricultural sector

c) Actions

i) Develop, and identify by 2017, drought- and flood- resistant, and salt- and temperature-tolerant varieties, of staple and commercial crops, drawing upon local and indigenous knowledge for commercial use. Regionally coordinated activity, undertaken in all Caribbean countries. Time frame for implementation: 2012 to 2016.

ii) Expand extension and support services for farmers. Time frame: 2011 to 2016.

iii) Research, and introduce by 2020, indigenous, and other, breeds of cattle, pig, goat and poultry that are heat-tolerant and more feed-efficient, for commercial meat, milk and egg production. Time frame: 2011 to 2017.

iv) Develop, and make available to farmers, grass, grain and forage legume species to support the production of meat, milk and eggs. Time frame: 2011 to 2016.

v) Develop, and promote, new and alternative food supplies and/or sustainable production systems, including sustainable land management. Time frame: 2012 to 2021.

vi) Implement fiscal, and other, policies and incentives to allow farmers and the private sector to invest in agriculture and food production in the Caribbean, without infringement of international trade regulations. Time frame: 2011 to 2016.

vii) Initiate Caribbean Community public education, awareness and outreach programmes on food, nutrition and health in the context of climate change. Create an enabling environment to facilitate behavioural change via fiscal incentives. Time frame: 2011 to 2021.

viii) Develop, and implement, strategies to secure, store and distribute food supplies and germplasm, particularly for use during low production periods and at times of natural disasters and other emergencies. Time frame: 2011 to 2016.

ix) Develop, and institutionalize, infrastructure and logistics to support post-harvest handling, transportation, distribution and marketing of food within and amongst individual Caribbean countries, based on needs and local conditions. Time frame: 2012 to 2021.

x) Caribbean Community and national emergency-preparedness institutions to become an integral part of the climate-change adaptation response strategy. Time frame: 2011 to 2021.

d) Outcome

Add value to agricultural production through processing:

xi) Develop, and implement, policies and other measures to promote investment in the processing of agricultural products, to add value and variety to output for food and other uses. Time frame: 2011 to 2021.

2. Key adaptation options

All the above-listed actions, which were based on the national communications to the United Nations Framework Convention on Climate Change by the countries of the Caribbean over the past decade, have sought to increase food security in the Caribbean.

The four main priorities for implementation, within the context of maximizing crop production, would be as follows:

Priority 1. Develop and identify for commercial use, by 2017, drought- and flood- resistant, and salt- and temperature-tolerant, varieties of staple and commercial crops, drawing upon local and indigenous knowledge. Regionally coordinated activity, undertaken in all Caribbean countries.

Time frame: 2012 to 2016.

Priority 2. Expand extension and support services for farmers.

Time frame: 2011 to 2016.

Priority 3. Develop and promote new and alternative food supplies and/or sustainable production systems, including sustainable land management.

Time frame: 2012 to 2021.

Priority 4. Develop and implement strategies to secure, store and distribute food supplies and germplasm, particularly for use during low production periods and at times of natural disasters and other emergencies.

Time frame: 2011 to 2016.

In addition, some individual countries, such as Saint Lucia, have identified a number of areas for focusing adaptation strategies. The key areas have been highlighted in annex 7. Those contributions have provided an additional template for assessing possible adaptation strategies for the Caribbean.

The present study has expanded on the proposed recommendations, and has ranked each adaptation option from high (score of 5) to low (score of 1) based on the internationally-proposed criteria for adaptation strategies. The initial rank of each proposal was based on resource availability and the policy environment in the Caribbean, and recognized existing adaptation activities or proposals that were currently being planned by the various Ministries of Food Production. Priority was given to on-farm adaptations. The rankings are shown in annex 8. Each of the criteria used had the same weight. Based on the eleven evaluation criteria, the top ten potential adaptation options were identified.

In general, adaptation options such as the use of soil conservation, which included mulching, that could allow the soil to retain more organic matter if organic mulches were used, reducing the loss of carbon from soil through lower soil loss became mitigation options as well. All adaptation options were important, but the options which focused on conserving and using water more efficiently were particularly important, given that rainfall levels were expected to decline in the Caribbean by 2050. Increased temperatures were expected to exacerbate heat stress in plants, especially when coupled with a decline in precipitation, so water conservation techniques (such as mulching) which conserved both soil and water were considered particularly relevant in adapting to climate change.

Establishing the benefits and costs associated with altering the crop calendar was identified as one of the top ten options; however, given the wide variety of crops produced in the Caribbean, and included in this analysis, a benefit cost analysis (BCA) was not conducted for this option.

The installation of protected agriculture, such as greenhouses, although it has received increased attention, was not considered readily suitable for root-crop production, being more useful for vegetable production. The installation of greenhouses, however, would reduce the quantity of fertilizers, pesticides and other synthetic chemicals normally used in the production process. As a result, there would be a lower demand for the energy and other inputs used in the cultivation of greenhouse crops, leading to a lower carbon footprint, if these savings could offset the increased energy use for cooling and irrigation systems in the greenhouse. Therefore, the BCA was conducted for the potential use of greenhouses as an adaptation option, given the increased focus being given to this technology in the Caribbean.

3. Benefit cost analysis of key adaptation options

The following ten options were used in the benefit cost analysis:

Option 1. Establishment of systems of food storage.

Option 2. Use of water-saving irrigation systems and water-management systems e.g. drip irrigation.

Option 3. Promotion of water conservation – installing on-farm water harvesting off rooftops.

Option 4. The design and implementation of holistic water management plans for all competing uses.

Option 5. Establishment of early-warning systems and disaster management plans for farmers.

Option 6. Adoption of improved technologies for soil conservation e.g. mulching.

Option 7. Construction of on-farm water storage (ponds, tanks, etc.)

Option 8. Development and introduction of drought-resistant crop varieties.

Option 9. Mainstreaming of climate change issues in agricultural policy.

Option 10. Installation of greenhouses

Given the costs and benefits for all adaptation options, which have been provided in the subsequent section, from 2012 to 2050, the present value of each option was calculated using a 4 per cent discount rate (table 21).

Estimates of benefits and costs were first calculated for Trinidad and Tobago,10 as cost data on individual countries were not available. Since the value of crops produced in Trinidad and Tobago in 2010 was US$ 173 million, and the total value of crops produced in the Caribbean in that year was US$ 4,263.1 million (excluding Dominica and Haiti), the benefit and cost values calculated for Trinidad and Tobago were scaled up (by 24.64) to estimate the total benefits and costs for the Caribbean, for all options except for the estimation of values for the early-warning system for farmers and the development of drought-resistant varieties.

The agricultural early-warning system for farmers and the development of drought-resistant varieties were calculated on a Caribbean Community-wide basis, considering the systems needed as independent projects. The final choice by Caribbean Governments should include these assessments, as well as the omitted, intangible benefits from the provision of other social goals, such as employment.

[10] Benefit-cost analysis of several of the listed adaptation options had been previously calculated for Trinidad and Tobago (ECLAC (2011a)) and, therefore, this country was used as a reference since data were readily available. This proved very useful since aggregating datasets of the requirements for calculating the cost of each adaptation for each Caribbean country would have been prohibitive.

Where wages have been computed, it has been assumed that wage rates rose by 2 per cent per annum. It was assumed that the rate of inflation was 5.8 per cent, which was the simple average inflation rate for the Caribbean, based on annual averages from 2007-2011.

TABLE 21
BENEFIT COST ANALYSIS OF KEY ADAPTATION OPTIONS FOR THE CARIBBEAN
(Millions of United States dollars)

	Details	Cumulative present value of benefits	Cumulative present value of costs	Benefit cost ratio	Net present value
Option 1	Systems of food storage	1 275.43	84.01	15.2	1 191.42
Option 2	Drip irrigation	1 669.26	1 300.57	1.3	368.70
Option 3	Water harvesting	667.72	340.70	2.0	327.02
Option 4	Water management plans	453.39	72.98	6.2	380.41
Option 5	Early warning systems	2 232.98	27.53	81.1	2 205.46
Option 6	Soil conservation	1 726.93	622.55	2.8	1 104.37
Option 7	On - farm ponds	115 873.26	589.93	196.4	115 283.33
Option 8	Drought resistant varieties	1 637.07	39.43	41.5	1 597.64
Option 9	Mainstream climate change	30 757.29	696.14	44.2	30 061.15
Option 10	Installation of greenhouses	192.30	50.69	3.8	141.61

Source: Author’s calculations based on United Nations Economic Commission for Latin America and the Caribbean (ECLAC), *An Assessment of the Economic Impact of Climate Change on the Agriculture Sector in Trinidad And Tobago*,(LC/CAR/L.321), United Nations Economic Commission for Latin America and the Caribbean, October, Port-of-Spain, Trinidad and Tobago, [online], [date of reference: August 2012], http://www.eclac.org/portofspain/noticias/paginas/0/44160/Trinidad_and_Tobago_lcarl321.pdf, 2011

All the suggested adaptation options were deemed to be socially acceptable projects as they had positive net present values. The options with the highest net present values were the construction of water conservation systems, such as on-farm ponds (US$ 115.283 billion), followed by mainstreaming climate change into all national policies (US$ 30.061 billion) and the establishment of an agricultural early-warning system (US$ 2.205 billion). The benefit cost ratio approach proved this outcome consistent with the top recommendation, which indicated that the construction of on-farm ponds was expected to produce US$ 196.40 in benefits for every US$ 1 invested.

However, the benefit cost analysis indicated that the second most-attractive option was the establishment of an agricultural early-warning system, followed by mainstreaming climate change into all Caribbean national policies. The establishment of ponds, while having a high return, was largely limited to flat areas, or areas with a gentle slope. The terrain is quite hilly in many parts of the Caribbean – such as Saint Vincent and the Grenadines, Dominica, and Saint Lucia – so that the use of open ponds would be limited. However, the use of covered, above- or below-ground water-storage tanks, which collected harvested rainwater, would be more suitable.

The use of on-farm ponds was expected to provide significant benefits through having a stable, on-farm water supply as, by the 2050s, rainfall was expected to decline by 29.6 per cent under A2 by the 2050s and by 16.2 per cent under the B2 scenario. With the expected increased temperatures over time, crops would have an increased demand for water, as evapotranspiration increased and soil-water loss intensified. From this perspective, having drought-resistant varieties would be a proactive strategy with a relatively low cost (US$ 39.43 million), but with a very high return on each dollar invested (a benefit-cost ratio of 41.5).

Options such as the use of drip irrigation and the installation of greenhouses had benefit-cost ratios of less than four. This was mostly due to the very high start-up costs associated with these kinds of high-technology innovations. While individual countries would select adaption options which best fitted their availability of investment funds, topography and national priorities, the

Caribbean would benefit most from having a mix of better legislative and management frameworks while, at the same time, introducing technical strategies.

The top five options, based on NPV, suggested that – while the installation of greenhouses have been becoming a more popular – an agricultural early-warning system at the Caribbean level would be even more important, as it would ensure that production losses were avoided, or lessened, with the use of information on the best agricultural practices to suit the expected weather conditions, especially in times of water stress. This early-warning system would provide forecasts of weather on short-term bases, such as for three months at a time, or for longer planning horizons, such as a year.

A system of food storage would be crucial after an extreme event, so that food aid could be mobilized across the Caribbean as needed. While each Caribbean country would be expected to have its own food stocks, an integrated system would allow for greater food security and availability for any Caribbean country in the event of need.

Drought-resistant varieties – which have at least as much yield as existing varieties – were expected to provide US$ 1.597 billion in net benefits up to 2050. While the current emphasis has been on varieties which offered good market characteristics (taste, yield, colour and shape), which provided immediate returns, the productivity of many of these varieties could decline over time as they might not be able to withstand reduced levels of rainfall. As a result, should there be no introduction of drought-resistant varieties, domestic and export earnings might decline, as the positive impacts of higher-yielding varieties could be eroded by the presence of water-sensitive stock.

Mainstreaming climate change into national policies would require an overall commitment, both to engage in mitigation activities, and to provide more energy-efficient systems. From the perspective of the agricultural sector, big components would include increasing water efficiency (especially from reduced system leakages), increasing use of renewable energy (which can reduce the cost of energy to farms) and improved watershed management (which would ensure adequate ground- and surface- water recharge to supply farm wells, and other water sources, for irrigation purposes). These changes, while outside the agricultural sector, would benefit agricultural producers, and have indicated that energy-efficiency would be the second most-valuable adaptation option for implementation in the Caribbean.

B. Assumptions used in calculating the costs and benefits of adaptation options

The cost benefit analysis considered the period 2012-2050.

1. Option one: establish systems of food storage.

It was assumed that:

- Storage would provide food for 315,392 meals at 450 grams per meal, in the event of a national emergency.
- Food storage consisted of dry/canned goods and grains, such as rice and wheat flour.
- The products stored were bought as a fiscal incentive and were owned by private firms, except in national emergencies, when ownership would revert to the State.
- No replacement silos would be needed during the project.
- Four silos would be installed. The details of the food storage costs are shown in table 22.

TABLE 22
BREAKDOWN OF FOOD STORAGE SYSTEM COSTS
(United States dollars)

Item		Cost	Reference
Ten-ton wheat silo at $ 5633		5 857	Moylan Grain Silos Kellerberrin (2011)
Shipping & handling		5 857	
	Sub-total	11 714	
Installation – labour		9 302	15 persons at $62.02/day for 10 days
	Total	21 017	
Four (4) warehouses (each of 7.62 m by 12.19 m) with holding capacity for 143 360 kg			
68.86 kg food per m^2			
2.44 m high stack			
70 per cent warehouse capacity			
Wheat price/metric tonne		303.81	IndexMundi (2011a)
Rice price /metric tonne		537.70	IndexMundi (2011b)
Emergency meals:		315 392	450 g food per meal

Source: Data compiled by Author

2. Option two: use water-saving irrigation and water-management systems[11]

It was assumed that:

- there was transformation of the 2008 land area under green vegetable cultivation from a rain-fed system to a drip irrigation system (Porter's Agri-Industrial Agencies Ltd., 2011), of 2 per cent or 0.375 km^2 per year for 20 years.
- the investment cost per km^2 for the drip irrigation system was $ 1.97 million.
- the replacement of drip lines occurred every five years.
- the revenue of green vegetables in 2008 was $ 18.00 million.
- irrigation of green vegetables increased yield by 30 per cent.
- the rate of inflation was 4 per cent.

3. Option three: promote water conservation – install on-farm water harvesting off rooftops

It was assumed that:

- water could be collected off the roofs of on-farm sheds or buildings.
- the length of each on-farm shed/storage unit was 6.10 m.
- the cost of two 4.55 m^3 tanks at $ 333.80 each, plus spouts and brackets was a total of $ 549.71.

[11] For example drip irrigation.

- the benefit of water harvesting would be 40 per cent of the benefit of drip irrigation per km^2.
- labour costs were $ 62.02/man day.
- a total of 3.05 m of down spouting and ten brackets on the downspouts would be required for two tanks.
- there were 13,874 holdings of crops in 2004 (Trinidad and Tobago, 2005).
- there would be a 2 per cent increase in holdings (by 110 holdings) per year with water harvesting technology.

4. Option four: design and implement holistic water management plans for all competing uses

It was assumed that:

- the design and implementation of an appropriate plan would result in an improvement in yield of 2 per cent of the 2008 value of green vegetables and root-crop yields.
- implementation would require four persons for a period of 12 months.
- follow-up would require six persons per year.
- there would be need for four stakeholder consultations at a cost of $ 930.23 each.
- administration costs would include: marketing, office supplies, travel costs, office equipment and services.
- the policy review and monitoring would occur every five years.
- follow-up administration costs would be 20 per cent of total cost for the first year.
- persons at a rank of Economist 1 would be employed to undertake the policy writing, at a salary of $ 1,550.39/month.

5. Option five: agricultural early warning systems

The early warning system (EWS) was assumed to be an integrated database of weather, climate, agronomic, economic and social data, which could be used to forecast the incidence of drought, flood, other extreme events, intensified pest and disease occurrence, and reduced food production capacity due to short-term changes in soil characteristics. The EWS could be a network of existing databases – such as already exist at the Caribbean Institute for Meteorology and Hydrology (based in Barbados) – or, in the case of socioeconomic data, robust, complete databases that need to be developed by stakeholders such as Central Statistical Offices, tertiary institutions, producer groups or marketing agencies that would use this kind of data to plan production and trade.

The development of the EWS assumed a minimum need for:

- Human resources:
  - 2 Information Technologists at US$ 30,000 per year each = US$ 60,000 per year
  - 32 Data Managers at US$ 25,000 per year for each country = US$ 800,000 per year
  - 4 Editors at US$ 25,000 per year each = US$ 100,000 per year
  - 2 Agronomists at US$ 30,000 per year each = US$ 60,000 per year.

  - The platform allowing connection of the various networks would require a Systems Analyst at US$ 35,000 in the initial year, and US$ 7,000 per year thereafter, for system maintenance.
- Equipment:
  - 11 laptops at US$ 3,000 each, to be replaced every five years
  - Server at US$ 10,000 to be replaced every eight years.

It was expected that benefits would be in the form of avoided losses, as a result of being able to provide timely data that would allow farmers to alter their crop calendars and maximize output per unit time, and/or provide safety nets and disaster management systems to be implemented on-farm to reduce losses.

It was also expected that, every year, such management would result in 1 per cent savings of total crop-yield value. This constant value would—possibly—be an overestimation of avoided losses in years for which there were no negative events, or an underestimation in years for which there were significant negative events.

In 2010, total crop values were US$ 4.218 billion (annex 1). It was assumed that setup required one year, so that benefits would begin to accrue in the second year.

6. Option six: adopt improved technologies for soil conservation

It was assumed that:

- total acreage under green vegetables plus root crops in 2008 was 63.94 km^2.
- one roll of polyethylene mulching sheet (for an area of 1,219.20 m by 1.22 m) would cost US$ 343.08 plus tax.
- the plastic mulch would be applied to 2 per cent of the land area under crop cultivation per year (1.28 km^2).
- the mulch application increased yield by 2 per cent on 1.28 km^2.
- there would be a 90 per cent reduction in the labour cost of weeding as a result of applying the mulch (CARDI, 2009).
- there would be an avoided cost for weedicide (except pre-emergent weedicide), labour, material and equipment cost for insecticide in tomato production (Adams and others, 2007).

7. Option seven: build on-farm water storage (ponds, tanks)[12]

It was assumed that:

- impoundments would be dug into the ground on-farm to collect surface runoff.
- the job of digging a pond would take five days.
- the cost of the excavator was $ 310.08/day.
- the truck to move soil cost $ 186.05/day.
- the track bobcat cost $ 279.07/day.

[12] In Ecuador, the average cost of constructing an on-farm pond was estimated at US$ 0.93/m^3 of water, but the range was from US$ 0.10/m^3 to US$ 2.00/m^3. (OAS, 2011). The operations and maintenance costs ranged between US$ 0.01/m^3 and US$ 0.03/m^3 of storage capacity. These cost estimates would be too low for the Caribbean.

- the cost of mobilization of the equipment to and from the job site would be US$ 310.08 each.
- the prices quoted included labour to operate the equipment.
- the on-farm ponds would be established on 1 per cent of crop holdings (138 holdings) per year for 10 years.
- the avoided crop losses would be the equivalent of 10 per cent of revenue on 138 farms (based on 2008 dollar values of green vegetables and root crops).
- total value of vegetables and root crops yield in 2008 was US$ 17,382,365.89.

8. Option eight: drought-resistant crop varieties

It has been assumed that research would focus, initially, on items which had the largest production in the Caribbean. The five key crops suggested for the development of drought-resistant varieties should be sugarcane, rice, bananas and plantains, cassava, and tomatoes.

Advanced stock could be sourced from international research centres which already have these germ plasm. Given the urgency of the introduction of improved varieties, it was estimated that the first selection of improved varieties for use by farmers would occur after three years.

For each crop, the following human resources would be needed:

- 3 doctoral scholars (part-time) at US$ 17,054 per year = US$ 51,162
- 1 Post-doctoral Fellow at US$ 17,054 per year + US$ 3,721 (housing) + US$ 4,186 (travelling allowance) = US$ 45,116
- 1 Grade 7 Technician at US$ 13,953 per year.

For each crop, additional annual expenses would include:

- Fertilizers at a cost of US$ 9,302
- cultivation at a cost of US$ 7,752
- labour (400 man-days at a cost of $ 31/man-day) equivalent to US$ 12,403
- miscellaneous costs, which include the maintenance of laboratories and equipment at a cost of US$ 9,302.[13]

The proposal would be for a 3 per cent switch every year from traditional varieties to the new, improved, drought-resistant varieties, until existing varieties have been completely replaced.

9. Option nine: Mainstream climate change issues into agricultural policy

It was assumed that:

- mainstreaming would require the review of all national policies and projects to ensure that climate change issues were included.
- the review of national policies would require the training of 150 workers per year at US$ 775/person (in-house training, conferences, travel of experts, study abroad, etc).
- an annual policy review would utilize 50 persons.

[13] These data were modified from Rekhi (2012).

- the salary of an Economist I would be US$ 1,336 (Brathwaite, 2011)
- there would be a 2 per cent annual rise in salaries
- annual GDP rises by 0.1 per cent
- the 2008 nominal GDP for Trinidad and Tobago was US$ 23,584 million (Trinidad and Tobago, 2009)

10. Option ten: Installation of greenhouses.

Assumptions of costs and benefits for the installation of greenhouses are provided in table 23.

TABLE 23
GREENHOUSE INSTALLATION COSTS
(United States dollars)

Item		Cost	Reference
Greenhouse Brand - 1 Southern Start Package		17 793	Greenhouse Megastore (2011)
S&H (20 per cent)		3 558	9.14 m by 14.63 m (9.07 kg rating, 1.83 m sidewall)
Taxes (15 per cent)		2 669	
Land preparation - labour and machinery		775	
Labour – installation		4 961	
Benches, drip irrigation		1 779	
	Total	31 535	
Construct 5 greenhouses per year for 10 years			
Traditional tomato yield for greenhouse-sized plot (kg)		2 363.32	Vital Earth Resources (1999)
Additional yield (proportion)		0.6	
Crops/year		5	
Additional yield for 5 crops (kg)		7 089.96	
Price/kg (2008)		1.40	

Source: Data compiled by Author

IX. Implications for food security of projected climate change impacts on the agricultural sector

In order to achieve food security, food must be available from either local or imported sources, in a form that is needed. Investment in the agricultural sector in several Caribbean countries has been declining over time, and has meant that total domestic agricultural production has not kept pace with increases in population and in the demand for food. Thus, per capita agricultural production has fallen steadily over time, associated with declining agricultural productivity. This has led to the rapid increase of the Caribbean food import bill, in many countries so high relative to the value of exports that it has become another threat to food security. Despite increasing wealth in many States, food has been increasingly more expensive in real terms compared to non-food items. In addition, incidences of drought in recent years have led countries to adopt more inward-looking food security policies: bans, or higher taxes, on exports. Furthermore, climate change in the Caribbean is expected to result in lower rainfall by 2050 and higher temperatures. Output of key agricultural commodities is expected to be adversely affected, and some persons employed, directly and indirectly, in the agricultural sector may lose their livelihoods, especially in rural areas.

Food security requires that food must not only be physically accessible, but affordable as well. A reduction in the production of key agricultural products may lead to an increase in the prices of these commodities, should they not be readily imported at favourable prices. Thus, consumers will be affected negatively and, in such cases where consumers can switch consumption easily to other products (goods with a low price elasticity of demand), producers will find that their total income falls even as prices rise for these commodities. Lower incomes for producers will threaten their livelihoods, in turn.

A third key element is that food must be safe (free of pests and disease) and provide adequate nutrition. The final component of food security is that the availability, accessibility, safety and nutritious nature of food must be stable at all times. Changes in climate which affect food quantities threaten the stability of food flows to consumers. In general, lowered supply of food domestically, constrained ability to afford imported food, and increased food prices will affect the food security of the Caribbean population unfavorably, with bigger impacts on poorer persons who, typically, spend a higher percentage of their incomes on foodstuffs.

The increasing pressure being put on scarce natural resources, such as land and water, and how such demands will be met in the future, will be key in determining the size of the natural resource endowment of the agricultural sector. Over time, increased demand for labour in the tourism sector in the Caribbean has drawn labour resources out of the agricultural sector as well, given that real wages in non-agricultural jobs are higher. In some countries in the Caribbean, the agricultural sector suffers from poor perception in society, in that the tasks involved were menial, unprofitable and risky (due to praedial larceny and weather risks). The lack of insurance for farmers adds to the risk. The threat of climate change adds a new burden to each country's agricultural sector. Adaptation options must be fast-tracked if the sector is to survive.

X. Conclusions

Significant losses were expected in the production of key agricultural crops as a result of climate change. Overall, forecast output of all crops was expected to fall by approximately 12 per cent under the A2 scenario by the 2050s, whereas under the B2 scenario, yield was projected to fall by 7 per cent over the same period.

Bananas and plantains were expected to have the largest decline in potential yield of the five crops selected, by approximately 33 per cent under the A2 scenario, which is considered the Business as Usual case. When compared to B2, the fall in yield would still be large, at almost 20 per cent. Rice was the only crop whose expected production showed a different pattern to the other crops. Under the A2 scenario, the predicted rice yield by fell by approximately 3 per cent by the 2050s but, in the B2 scenario, predicted rice yield was expected to rise by approximately 2 per cent over the same period. Rice was expected to have the best outcome, largely due to the CO2 fertilization effect of this C3 plant, versus the other crops, which are C4 plants.

Across both rain-fed and irrigated systems, sugarcane was expected to have a 13 per cent drop in projected yield under A2 by the 2050s, and a 9.6 per cent drop under B2 for the same period. Cassava was projected to have a 22.2 per cent drop in potential yield under A2 by the 2050s and a 1.2 per cent drop under B2 for the same period. Yams were estimated to outperform cassava, with a 14.7 per cent drop in potential yield under A2 by the 2050s, but only a 6.3 per cent drop under B2 for the same period. Under the Business as Usual case (A2), sweet potato was anticipated to experience a 2.4 per cent decline in forecast yield by the 2050s and a 6.9 per cent decline under the B2 scenario. Tomatoes would be likely to suffer significant declines in potential yield, of 28.1 per cent under A2 and 16.9 per cent under B2, by the 2050s.

The relative impacts differed by crop under the A2 and B2 scenarios but, in general, the negative impacts appeared to be worse under A2, the longer the planning horizon. At a 1 per cent discount rate, the agricultural sector would be expected to suffer losses of approximately US$ 4.2 billion for the Business as Usual case under A2, and less than half that amount, US$ 1.8 billion, under the B2 scenario.

Based on the area of currently cultivated land, changes in crop suitability categories were varied by crop. By the 2050s, significantly more land was deemed as unsuitable for rain-fed cassava production using intermediate inputs, under the A2 scenario, relative to the B2.

Under the A2 scenario, more than 70 per cent of the land that had been deemed as very highly suitable for irrigated sugarcane production using intermediate inputs, was no longer in this classification by the 2050s, whereas under the B2 scenario, approximately 50 per cent of land in this classification was lost.

Sea-level rise impacts in the agricultural sector for the Caribbean were likely to be negligible. Positive impacts were noted only for Jamaica (US$ 3.9 million in losses in 2050) and the Bahamas (US$ 0.1 million loss in 2050).

Ten key climate change adaptation strategies for the agricultural sector have been suggested for implementation in the Caribbean. These are:

- Establish systems of food storage
- Use water saving irrigation systems and water management systems e.g. drip irrigation
- Promote water conservation – install on-farm water harvesting off rooftops
- Design and implement holistic water management plans for all competing uses
- Establish early warning systems and disaster management plans for farmers
- Adopt improved technologies for soil conservation e.g. mulching
- Build on- farm water storage (ponds, tanks etc)
- Develop and introduce drought-resistant crop varieties
- Mainstream climate change
- Install protected agricultural structures e.g. greenhouses.

All of the climate change adaptation options have positive net benefits. The options with the highest net present value were the construction of water conservation systems such as on-farm ponds (US$ 115.283 billion), followed by mainstreaming climate change into all national policies (US$ 30.061 billion) and the establishment of an agricultural early warning system (US$ 2.205 billion).

This outcome was consistent with the top recommendation derived using the benefit cost ratio approach, which indicated that the construction of on-farm ponds would be expected to produce US$ 196.40 in benefits for every US$ 1 invested. However, the benefit cost ratio indicated that the second most attractive option would be the establishment of an agricultural early warning system, followed by mainstreaming climate change into all national policies. Other options, such as the introduction of drought-resistant varieties and the implementation of a Caribbean system of food storage, were also highly recommended.

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Annexes

Annex 1

TABLE A1
CROP AND LIVESTOCK PRODUCTION VALUES FOR THE CARIBBEAN, 1991-2010
(United States dollars)

Year	Total crop production value	Total livestock value
1991	901 176 336	430 107 989
1992	888 846 008	408 120 525
1993	900 888 221	392 125 923
1994	1 024 503 476	351 125 963
1995	1 650 510 699	428 124 310
1996	1 785 850 672	539 276 946
1997	2 875 360 375	590 218 145
1998	2 760 368 742	591 472 970
1999	2 719 183 389	650 082 840
2000	2 560 326 758	697 109 766
2001	2 615 926 207	687 858 355
2002	2 522 952 921	742 114 763
2003	2 590 396 795	756 637 298
2004	3 165 667 136	785 040 714
2005	3 297 176 035	858 508 144
2006	3 613 611 994	850 967 179
2007	4 145 853 508	1 091 061 179
2008	4 317 915 508	1 197 160 678
2009	4 117 981 581	1 221 581 824
2010	4 218 823 084	1 334 714 411

Source: Compiled by the author based on data from Food and Agriculture Organization of the UnitedNations (FAO), and local country data

ANNEX 2

TABLE A2
KEY CARIBBEAN AGRICULTURAL PRODUCTS RANKED BY VALUE, 2010

(Thousands of International dollars and tonnes)* *Gross production values (constant 2004-2006 1000 I$)

Commodity	Production (Int. $'000)	Production (tonnes)	Commodity	Production (Int. $'000)	Production (tonnes)
Antigua and Barbuda			Guyana		
Fruit, tropical fresh nes	2 616	6 400	Rice, paddy	154 991	556 200
Cow milk, whole, fresh	1 779	5 700	Sugarcane	90 706	2 762 300
Indigenous cattle meat	1 513	560	Indigenous chicken meat	35 367	24 829
Mangoes, mangosteens, guavas	779	1300	Cow milk, whole, fresh	13 450	43 100
The Bahamas			Haiti		
Indigenous chicken meat	8 884	6 237	Mangoes, mangosteens, guavas	130 858	218 400
Grapefruit	4 294	19 100	Indigenous cattle meat	121 562	45 000
Lemons and limes	4 044	10 200	Bananas	94 346	335 000
Vegetables fresh nes	3 373	17 900	Yams	90 031	353 000
Barbados			Jamaica		
Indigenous chicken meat	20 879	14 658	Indigenous chicken meat	145 560	102 190
Sugar cane	8 498	258 800	Goat milk, whole, fresh	59 733	178 000
Indigenous pigmeat	4 235	2 755	Sugar cane	43 824	1 334 600
Cow milk, whole, fresh	2 091	6 701	Yams	34 886	136 785
Belize			St. Kitts and Nevis		
Oranges	45 841	237 200	Fruit, tropical fresh nes	658	1 610
Sugarcane	30 135	917 728	Indigenous cattle meat	264	98
Bananas	19 742	70 100	Indigenous chicken meat	212	149
Indigenous chicken meat	18 336	12 873	Hen eggs, in shell	200	241
Cuba			Saint Lucia		
Sugar cane	371 058	11 300 000	Bananas	14 926	53 000
Indigenous pigmeat	264 919	172 334	Indigenous pigmeat	2 098	1 365
Cow milk, whole, fresh	196 442	629 500	Indigenous chicken meat	1 988	1 396
Tomatoes	191 065	517 000	Fruit tropical fresh nes	1 553	3 800
Dominica			Saint Vincent and the Grenadines		
Bananas	5 914	21 000	Bananas	17 602	62 500
Yams	3 902	15 300	Roots and tubers, nes	2 309	13 500
Taro (cocoyam)	3 627	17 100	Mangoes, mangosteens, guavas	959	1 600
Grapefruit	3 597	16 000	Yams	893	3 500
The Dominican Republic			Suriname		
Indigenous chicken meat	447 691	314 300	Rice, paddy	63 168	226 686
Indigenous cattle meat	305 066	112 930	Bananas	26 550	94 272
Papayas	257 826	908 462	Indigenous chicken meat	16 006	11 237
Bananas	207 012	735 045	Indigenous cattle meat	5 075	1 879

(continues)

Table A2 (continued)

Commodity	Production (Int. $'000)	Production (tonnes)	Commodity	Production (Int. $'000)	Production (tonnes)
Antigua and Barbuda			Guyana		
Grenada			Trinidad and Tobago		
Mangoes, mangosteens, guavas	1 258	2 100	Indigenous chicken meat	92 246	64 761
Avocados	1 178	1 700	Fruit fresh nes	17 312	49 600
Hen eggs, in shell	1 161	1 400	Indigenous pigmeat	4 614	3 001
Nutmeg, mace and cardamoms	1 041	500	Hen eggs in shell	3 566	4 300

Source: Food and Agriculture Organization of the United Nations (FAO), FAOSTAT online database, December, 2012

ANNEX 3

TABLE A3
FEMALE WORKERS IN AGRICULTURE IN THE CARIBBEAN
(Percentage)

YEAR	ANTIGUA	THE BAHAMAS	BARBADOS	BELIZE	CUBA	DOMINICA	THE DOMINICAN REPUBLIC	GRENADA	GUYANA	HAITI	JAMAICA	ST KITTS AND NEVIS	ST LUCIA	STVINCENT & THE GRENADINES	SURINAME	TRINIDAD & TOBAGO
1980										53.10						8.60
1981			8.90							52.00						9.50
1982			8.50							49.60						6.40
1983			7.70							49.60						6.10
1984			7.80									13.80				7.60
1985			7.20													7.50
1986			7.50													7.60
1987			6.70													7.30
1988			6.60					14.80		49.60						8.80
1989			6.60			12.70										7.70
1990			5.50							49.60					2.20	6.30
1991		1.50	4.40			13.20	2.60							13.90		6.40
1992		1.50	4.20				2.70				15.90				3.20	5.50
1993		1.40	4.50	4.70			2.80				12.00		14.90		2.30	5.60
1994		1.60	4.30	4.50			2.20	13.20			12.10		17.70		2.30	6.20
1995		1.10	3.60	6.10	13.20		1.70				11.70		17.70		3.30	5.00
1996		1.20	4.30	5.00	13.20		3.50	11.90			11.30		18.80		1.80	4.50
1997		2.20	4.20	6.10	13.20	13.70	2.20		16.30		10.10		13.80		2.90	3.90
1998		1.30	3.60	5.40	11.50		2.40	9.70			9.90		16.50		3.20	3.40
1999		0.90	3.30	6.40	14.20	16.10	2.80			37.30	8.90		15.90		1.80	2.80
2000			3.30		14.20		2.50				9.20		14.30			2.90
2001	1.10	1.40	3.60		9.20	8.30	1.90		16.30		9.60	0.10		7.60		3.10
2002	1.20	1.70	3.10		9.20		1.90		7.10		9.90		8.70			2.00
2003	1.20	0.60	3.50		9.20		1.70				8.80		8.50			2.00
2004	1.20	0.40	2.50		10.10		1.90				8.80		9.80		4.50	2.00
2005	1.20	0.30		3.30	9.40		2.80				8.50					1.70
2006	1.20	0.50			9.40		2.20				8.30					2.00
2007	1.20	0.20			8.60		2.10				8.10					1.80
2008	1.20	0.70			8.50		2.20				9.40					1.80
2009		0.50					2.10				9.60					

Source: World Bank, "Data" [online database] [date of reference: December 2012] <http://data.worldbank.org/>

ANNEX 4

TABLE A4
HADLEY AVERAGE ANNUAL TEMPERATURE PROJECTIONS, BY CARIBBEAN COUNTRY BY DECADE UNDER A2 AND B2 EMISSIONS SCENARIOS, 2020s-2050s
(Degrees Celsius (°C))

		A2		B2	
Country	Baseline	2020s	2050s	2020s	2050s
Antigua and Barbuda	26.36	27.01	27.80	27.18	27.64
The Bahamas	24.84	25.65	26.61	25.71	26.36
Barbados	25.92	26.56	27.31	26.66	27.14
Belize	25.08	26.23	27.50	26.22	27.06
Cuba	25.12	26.09	27.20	26.10	26.89
Dominica	24.39	25.03	25.79	25.18	25.63
The Dominican Republic	24.12	25.03	26.02	25.14	25.74
Grenada	25.51	26.24	27.03	26.31	26.83
Guyana	26.02	27.40	28.87	27.36	28.26
Haiti	24.29	25.23	26.26	25.33	25.96
Jamaica	25.32	26.15	27.08	26.23	26.84
Saint Kitts and Nevis	25.52	26.18	26.96	26.35	26.81
Saint Lucia	26.21	26.86	27.62	26.98	27.45
Saint Vincent and the Grenadines	25.13	25.81	26.57	25.90	26.39
Suriname	26.32	27.52	28.93	27.54	28.40
Trinidad and Tobago	26.07	26.88	27.73	26.90	27.46

Source: Author’s calculations based on PRECIS Caribbean model projections

ANNEX 5

TABLE A5
HADLEY WEIGHTED ANNUAL RAINFALL PROJECTIONS, BY CARIBBEAN COUNTRY BY DECADE UNDER BASELINE, A2 AND B2 EMISSIONS SCENARIOS, 2020s-2050s

(Millimetres)

Country	Baseline	A2		B2	
		2020s	2050s	2020s	2050s
Antigua and Barbuda	1 468	1 311	1 072	1 333	1 262
The Bahamas	1 095	1 079	1 011	1 123	1 062
Barbados	1 353	1 101	911	1 116	1 104
Belize	2 214	1 995	1 766	2 087	2 057
Cuba	1 191	1 136	1 043	1 190	1 139
Dominica	2 229	1 848	1 467	1 867	1 756
The Dominican Republic	1 297	1 141	923	1 210	1 141
Grenada	1 450	1 141	917	1 176	1 141
Guyana	1 893	1 539	1 252	1 580	1 511
Haiti	1 014	890	716	935	884
Jamaica	794	729	622	750	717
Saint Kitts and Nevis	1 193	1 074	855	1 089	1 018
Saint Lucia	1 780	1 441	1 162	1 461	1 405
Saint Vincent and the Grenadines	1 683	1 355	1 103	1 380	1 345
Suriname	2 138	1 761	1 357	1 726	1 621
Trinidad and Tobago	1 677	1 305	1 053	1 355	1 342

Source: Author’s calculations based on PRECIS Caribbean model projections

ANNEX 6

TABLE A6
POTENTIAL SUGARCANE PRODUCTION CAPACITY ON CURRENTLY CULTIVATED LAND IN THE CARIBBEAN UNDER BASELINE, A2 AND B2 EMISSIONS SCENARIOS (2020s and 2050s)

SUGARCANE – IRRIGATED			Potential production with CO_2 (tonnes per hectare)			
			2020s		2050s	
Country	Harvested area (hectares)	Baseline	A2	B2	A2	B2
Antigua and Barbuda	0	5.05	4.43	4.42	4.41	4.41
The Bahamas						
Barbados	8 700	7.33	6.27	6.25	5.82	5.85
Belize	114	5.26	5.23	5.21	3.43	3.62
Cuba	456 570	6.02	5.99	5.99	5.50	5.58
Dominica						
The Dominican Republic	61 811	6.74	6.28	6.38	5.97	6.14
Grenada	150	6.60	6.59	7.23	4.80	5.44
Guyana	42 013	2.84	2.82	2.83	2.80	2.81
Haiti	9 271	6.35	5.90	6.09	5.57	5.86
Jamaica	7 803	4.81	4.52	4.47	4.28	4.35
Saint Kitts and Nevis	3 440	6.71	6.39	7.44	4.79	5.01
Saint Lucia	0	4.79	4.44	4.92	4.32	4.75
Saint Vincent and the Grenadines						
Suriname	2 766	3.87	3.76	3.78	3.77	3.68
Trinidad and Tobago	25 000	3.71	3.57	3.65	3.37	3.56
Caribbean	617 638	5.78*	5.69	5.70	5.26	5.35

Source: Author's calculations

Note: *=weighted average

TABLE A7
POTENTIAL RICE PRODUCTION CAPACITY ON CURRENTLY CULTIVATED LAND IN THE CARIBBEAN UNDER BASELINE, A2 AND B2 EMISSIONS SCENARIOS (2020s and 2050s)

COUNTRY	RICE		Potential production with CO_2 (tonnes per hectare)			
			2020s		2050s	
	Harvested area (hectares)	Baseline	A2	B2	A2	B2
Antigua and Barbuda	0	5.33	5.46	5.62	5.81	5.71
The Bahamas						
Barbados	0	5.37	5.51	5.49	5.64	5.56
Belize	3 479	5.06	4.30	5.15	4.35	5.17
Cuba	157 265	4.39	5.07	4.46	5.20	4.52
Dominica						
The Dominican Republic	98 184	4.23	4.30	4.27	4.38	4.30
Grenada	0	1.83	1.86	1.86	1.89	1.87
Guyana	57 818	2.48	2.29	2.48	2.16	2.47
Haiti	43 457	3.21	3.07	3.25	3.13	3.27
Jamaica	13	3.78	3.85	3.82	3.92	3.86
Saint Kitts and Nevis		5.57	5.71	5.68	5.86	5.76
Saint Lucia		2.07	2.10	2.09	2.13	2.11
Saint Vincent and the Grenadines						
Suriname	42 289	3.86	0.00	3.88	0.00	3.82
Trinidad and Tobago	2 150	3.66	3.35	3.72	3.41	3.76
Caribbean	404 656	3.90	3.73	3.94	3.78	3.97

Source: Author’s calculations

Note: *=weighted average

ANNEX 7

TABLE A8
KEY AGRICULTURAL CHALLENGES AND INVESTMENT FOCUS FOR THE CARIBBEAN

Problems	ATG	BHS	BRB	BLZ	CUB	DMA	DOM	GRD	GUY	HTI	JAM	KNA	LCA	VCT	SUR	TTO
Inadequate food storage and processing capacity	x	x		x	X			x		x	x					x
Level of competitiveness/productivity/marketing		x	X	x	X				x		x	x	x	x		
Land use/resources and water availability			X		X	x			x		x		x		x	x
Pests and diseases				x				x		x				x		
Inadequate human resources and extension/professional services		x	X	x		x	x	x	x		x	x	x		x	
Natural disasters/weather related issues	x		X		X	x		x			x		x	x		
Weak legislation/policy/institutional framework		x				x			x			x			x	
Lack of financial support/investment	x	x	X		X	x							x		x	
Environmental concerns		x					x				x					
Poor irrigation/drainage, roads and transportation					X		x		x	x	x	x				X
Lack of improved technology		x		x			x		x			x			x	X
Poor record keeping	x	x													x	
Commodity insurance		x													x	X
Key areas to work on																
Infrastructure (storage/processing facilities, drainage, grading, maintenance, etc)	x	x		x	X		x		x	x	x	x	x		x	X
Food safety and quality		x	X					x	x			x			x	
Productivity/competitiveness		x	X	x	X			x	x		x	x	x	x		
Technology		x	X				x	x	x			x			x	X
Research and development/training/technical support/labour	x	x	X	x		x	x	x	x		x	x	x		x	
Supporting legislative and institutional framework		x				x			x		x	x	x		x	

(continues)

Table A8 (continued)

Problems	ATG	BHS	BRB	BLZ	CUB	DMA	DOM	GRD	GUY	HTI	JAM	KNA	LCA	VCT	SUR	TTO
Pest and disease management		x												x		
Investment and financial support	x	x	x		X	X	x						x		x	x
Environmental management		x									x		x			

Sources: **ATG:** Antigua and Barbuda, 2008; United Nations Department of Economic and Social Affairs (UNDESA), 2012, **BHS:** Inter-American Institute for Cooperation in Agriculture (IICA), 2012c; Food and Agriculture Organization (FAO), 2009, **BRB:** Rawlins, G., n.d., **BLZ:** Belize, 2010, **CUB:** United States Department of Agriculture (USDA), 2009, **DMA:** Dominica, 2012; IICA, 2012b, **DOM:** World Bank, 2009; de los Santos and Peña (2007), **GRD:** Grenada, 2009; 2011, **GUY:** Guyana, 2000; 2013, **HTI:** Haiti, 2010, **JAM:**, **KNA:** IICA, 2012a; **LCA:** Saint Lucia, 2010, **VCT:** St. Vincent and the Grenadines, 2000, **SUR:** Caribsave (2012); Technical Centre for Agricultural and Rural Cooperation (CTA) (2005), **TTO:** Trinidad and Tobago, 2012

ANNEX 8

TABLE A9
POTENTIAL RISKS AND ADAPTATION OPTIONS FOR THE CARIBBEAN

Risk	Source	Adaptation option	Evaluation criteria											
			Low cost	Effectiveness	Acceptance to stakeholders	Endorsement by experts	Short time frame	Institutional capacity	Size of beneficiary group	Ease of implementation	Adequacy for current climate	Potential positive social/environmental impact	Potential to sustain over time	Score
↓ Water Availability	↓ Rainfall	Use water-saving irrigation and water-management systems e.g. drip irrigation	M	M	H	H	H	H	H	H	H	H	M	49
		Build on-farm water storage (ponds, tanks etc)	H	H	M	M	M	H	M	M	H	H	M	43
		Promote water conservation – install on-farm water harvesting off roof tops	L	M	M	H	H	H	H	H	H	H	H	47
		Install protected agricultural facilities	M	H	M	M	H	L	M	L	H	H	M	37
		Change agronomic practices e.g. mulching	M	H	L	H	H	M	H	M	H	H	M	43
		Change water pricing to reflect increasing scarcity	M	M	L	H	H	L	H	L	H	H	M	39
		Build new dams	L	H	M	H	L	M	H	L	H	M	M	35

(continues)

Table A9 (continued)

Risk	Source	Adaptation option	Evaluation criteria											
			Low cost	Effectiveness	Acceptance to stakeholders	Endorsement by experts	Short time frame	Institutional capacity	Size of beneficiary group	Ease of implementation	Adequacy for current climate	Potential positive social/environmental impact	Potential to sustain over time	Score
		Design and implement holistic water management plans for all competing uses	M	H	H	H	M	H	H	L	H	H	H	47
		Repair/maintain existing dams	L	H	H	L	M	M	M	M	H	H	M	37
		Provide fiscal incentives for water conservation	L	H	M	M	M	L	H	M	H	H	M	37
		Establish germplasm bank of native drought tolerant varieties	L	M	M	H	L	L	M	M	M	H	M	31
		Mainstream climate change issues into agricultural management	M	M	H	H	L	H	H	L	H	H	M	41
		Alter crop calendar for short-term crops	H	H	H	H	H	H	H	H	L	H	H	51
	↑ incidence of drought	Introduce more drought resistant varieties	M	H	H	H	M	L	H	M	H	H	M	43
		Implement land policy to retain high quality land	L	H	H	H	L	M	H	L	H	H	L	37
		Build new desalination plants to meet water-demand deficit	L	H	M	M	L	L	H	L	H	H	M	33

(continues)

Table A9 (continued)

Risk	Source	Adaptation option	Evaluation criteria

Risk	Source	Adaptation option	Low cost	Effectiveness	Acceptance to stakeholders	Endorsement by experts	Short time frame	Institutional capacity	Size of beneficiary group	Ease of implementation	Adequacy for current climate	Potential positive social/environmental impact	Potential to sustain over time	Score
		Utilise more groundwater sources	L	M	L	L	M	M	M	M	H	M	H	31
Agricultural land loss	Sea-level rise	Build defensive sea walls	L	H	M	M	L	M	L	M	L	M	H	29
		Relocate agricultural production	M	H	M	H	M	M	L	M	L	M	H	35
Soil salinization and reduced land quality	Sea-level rise	Develop/introduce salt tolerant/ resistant crop varieties	L	M	H	M	L	L	L	L	L	H	H	27
↑ Flooding	↑ Intensity of tropical storms	Establish systems of food storage	M	H	H	H	H	H	H	M	H	H	H	51
		Improve agricultural drainage systems	L	M	H	H	M	M	M	M	H	H	M	39
		Establish early warning systems and disaster management plans for farmers	L	H	H	H	M	M	H	M	H	H	H	45
		Establish a crop and livestock insurance scheme	L	H	M	H	L	L	H	L	H	H	M	35
↑ Pest and disease outbreaks	Change in temperature and rainfall patterns	Establish R&D for adoption of cultural/ biological control measures	L	H	H	H	L	L	H	L	H	H	M	37

(continues)

Table A9 (continued)

Risk	Source	Adaptation option	Evaluation criteria

		Low cost	Effectiveness	Acceptance to stakeholders	Endorsement by experts	Short time frame	Institutional capacity	Size of beneficiary group	Ease of implementation	Adequacy for current climate	Potential positive social/environmental impact	Potential to sustain over time	Score
↑ Sea surface temperature	Establish aquaculture facilities	L	H	M	H	H	L	M	M	H	M	M	37
Increase # of Extension Officers		M	M	M	M	M	L	H	L	H	M	M	33

Source: Data compiled by author.

Note: HIGH/YES=5; MEDIUM=3;LOW/NO=1
Many of the adaptation options reviewed were obtained from Saint Lucia (2010).