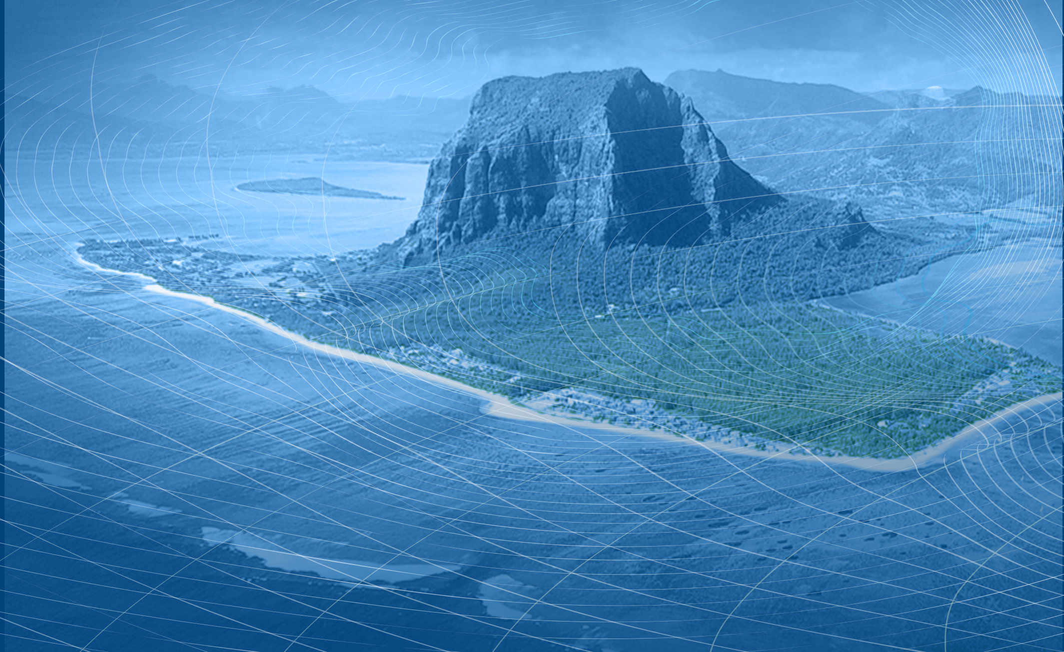
Agro-ecological Assessment
Methodology and Results

Climate, Land, Energy & Water Strategies

A Case Study of Mauritius



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Climate, Land, Energy and Water Strategies (CLEWS)
Case study of Mauritius

Agro-ecological Assessment
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Abstract

The study of the Island of Mauritius presented here is a collaborative effort between the International Atomic Energy Agency in Vienna, the Royal Swedish Institute of Technology in Stockholm, the Agricultural Research & Extension Unit in Quatre Bornes, Mauritius and the International Institute for Applied Systems Analysis (IIASA).

The Climate, Land, Energy and Water Strategies project (CLEWS) deals with integration of water, energy and land-use models to quantify resource use, greenhouse gas emissions and costs associated with meeting energy, water and food security goals. For this purpose the WEAP water model, the LEAP energy model and the AEZ land production planning tool were applied in an integrated fashion to determine (a) crop suitability under rain-fed and irrigated conditions for current and future projected climate, (b) potentials of bio-fuel feedstock crops, (c) the practicality and impact of crop changes, and (d) measures to ensure adequate water supplies in the face of an observed and projected trend of decreasing rainfall.

A core component in this study is the assessment of alternative land and water use options in view of anticipated climate change and socio-economic trends. For this purpose the agro-ecological zones (AEZ) methodology and database framework has been applied at a resolution of 3 arc-seconds (ca. 100 m grid). Climate change results indicate significant changes in rain-fed crop production potentials, particularly a decline in the northern and western parts of the island.

Results show that total water resources availability is expected to diminish due to climate change while water demand for agriculture, industrial and domestic use is increasing. This will trigger planning for extra water storage systems, for an overall expansion and upgrading of current water supply infrastructure, but also and foremost for more efficient use of water resources, in particular for irrigation. The high water demand of the dominating sugarcane production on the island may locally require the introduction of alternative less water demanding cropping systems.

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Preface/Acknowledgement

Land, energy and water are our most precious resources, but the manner and extents to which they are exploited is contributing to climate change. At the same time the systems that provide these resources are themselves highly vulnerable to changes in climate. Efficient management of these resources is therefore of great importance, both to mitigate the effects of climate change and to deal with its consequences. The research initiative CLEWS (Climate, Land, Energy and Water Strategies) has developed a new paradigm for comprehensive integration in resource assessments and policy formulation to avoid inconsistent strategies and inefficient use of resources (Howells et al., 2013 forthcoming). The CLEW project is a collaborative effort supported by a number of international organizations including FAO, IAEA, IIASA, SEI-US, UNDESA, and UNIDO.

The International Institute for Applied Systems Analysis (IIASA), in collaboration with the Food and Agriculture Organization of the United Nations (FAO), has developed an integrated agro-ecological zones (AEZ) modeling and database framework for assessment of alternative options for food security and sustainable agricultural development. This IIASA/FAO methodology has been applied as a core component in the case study of Mauritius.

Besides the study presented here on land use and agricultural potentials, two related studies looking at CLEWS aspects in Mauritius specifically from the energy and water resource side are also being published currently. This set of publications is based on common assumptions and data, and is developed to serve as an example of an integrated resource assessment illustrating the strong interrelation between the CLEW resources.

We would like to thank those who have provided most useful input in the development of this work: Mark Howell from the Royal Institute of Technology (KTH) for coordinating the CLEWS Mauritius analysis, Indoomatee Rama from the Mauritian Agricultural Research and Extension Unit for data collection and local expertise, Holger Rogner from the International Atomic Energy Agency and Manuel Welsch of KTH.

Contents

1 Background

The Republic of Mauritius is a small island country in the Indian Ocean, 950 km to the east of Madagascar. It has a land surface area of 1865 km^2 and is volcanic in origin with a central plateau surrounded by mountain ranges and plains. The highest peak on the island has an elevation of 828 meters above sea level. The island has a tropical maritime climate consisting of two seasons: summer, which lasts from November to April and is the rainier season, and winter, which is cooler and relatively dry. Average annual temperatures range from 20 to 25°C and rainfall ranges widely from 600 mm to 4000 mm depending on elevation and position relative to the prevailing winds.

Sugar production has been of strategic importance for the country for decades. Since 1975, Mauritius has had an export quota of about 500,000 tons per year under the Sugar Protocol of the Lomé Convention. The convention links European Union imports to the African, Caribbean and Pacific (ACP) countries' exports. Currently over 95% of the sugar produced in the country is exported to the European Union. However, it is likely that this sector will undergo substantial changes in the wake of the reform of the EU sugar import regime. Accordingly, the government has formulated several measures to refocus agriculture. A multi-annual adaptation strategy and action plan highlighting the steps to be taken has been prepared. As a consequence of the government's "diversification" policy, many planters with access to irrigation have diversified from sugarcane to food crops and vegetables; others are assessing a shift towards ethanol rather than sugar production from sugarcane. One national strategy document specifically commits Mauritius to producing a target of 30 million liters of ethanol annually by 2015 (GoM 2005) either for domestic blending with gasoline or export.

2 The Agro-ecological Zones Methodology

The Food and Agriculture Organization of the United Nations (FAO), in collaboration with the International Institute for Applied Systems Analysis (IIASA), has developed the agro-ecological zones (AEZ) methodology (Fischer et al. 2012) for the assessment of agro-ecological potentials of agricultural crops as well as for specific biofuel crops and perennial grasses.

For this study the crop production potential of current farmland, as well as other land was estimated and calibrated using AEZ techniques.

First, crop production potential of the island was estimated for reference climate (period 1961-90) and compared with known output values. Then the impact (in terms of yield and water requirements) of changing from sugarcane to alternative bio-energy feedstocks, cash crops, or food crops was estimated. The potential production (and water requirement) was assessed for:

(i) ***bioenergy feedstocks*** (**sugarcane↓, cassava↑**, jatropha, miscanthus);
(ii) ***oil crops*** (**groundnut↑↓→,** soybean);
(iii) ***cash crops*** (**citrus↑**, **coconut↑**, **banana↑**), and
(iv) ***cereals*** (**maize↓↓**).

Note: in bold are crops currently grown while ↓=declining, ↑ =increasing, and →= similar over the last 30 years.

Crop potential yield and production were simulated under the assumption of high input and management circumstances. Based on crop water requirements and crop cycle water balance, estimates of the volume of irrigation water required were made. The latter served as input into the WEAP water model.

2.1 Agro-ecological zones

The quality and availability of land and water resources, together with important socio-economic and institutional factors, is essential for crop production potential. Crop cultivation potential describes the agronomically possible upper limit for the production of individual crops under given agro-climatic, soil and terrain conditions for a specific level of agricultural inputs and management conditions. The Agro-ecological Zones (AEZ) approach is based on principles of land evaluation and is scale neutral assessment procedures (FAO 1976, 1984a and 2007), as may be well demonstrated by this relatively detailed Mauritius study performed with the same philosophy, models and algorithms comparable with global and regional assessments, but with much more spatially detailed biophysical data layers. The AEZ concept was originally developed by FAO. FAO, with the collaboration of IIASA has over time, further developed and applied the AEZ methodology, supporting databases and software packages. The current Global AEZ (GAEZ v3.0, Fischer et al. 2012) provides a major update of data and extension of the methodology compared to the previous release of GAEZ v2.0 in 2002 (Fischer et al. 2002a). GAEZ v3.0 produces two important new global spatial data sets, namely on “Actual Yield and Production’ and “Yield and Production Gaps”.

Geo-referenced climate, soil, terrain and land cover data are combined into a land resources database, commonly assembled on the basis of global grids, typically at 5 arc-minute and 30 arc-second resolutions; in this case of Mauritius a resolution of 3 arc seconds was used for terrain characterization.

The climatic data comprises precipitation, temperature, wind speed, sunshine hours and relative humidity, which are used to compile agronomically meaningful climate resources inventories including quantified thermal and moisture regimes in space and time.

Screening procedures to identify crop-specific limitations of prevailing climate, soil and terrain resources and evaluation with simple and robust crop models, under assumed levels of inputs and management conditions, provides estimates of maximum potential and agronomically attainable crop yields for basic land resources units under different agricultural production systems defined by water supply systems and levels of inputs and management circumstances. These generic production systems used in the analysis are referred to as Land Utilization Types (LUT).

Attributes specific to each particular LUT include crop information such as crop parameters (harvest index, maximum leaf area index, maximum rate of photosynthesis, temperature sum requirements, etc.), cultivation practices and input requirements, and utilization of main produce, crop residues and by-products.

Several calculation steps are applied at the grid-cell level to determine potential yields for individual crop/LUT combinations. Growth requirements of the crop species are matched against a detailed set of agro-climatic and edaphic land characteristics derived from the land resources database. Estimation of crop evapotranspiration and crop-specific soil moisture balance calculations are used for estimating crop/LUT specific suitability and potential productivity.

Spatial patterns of actual yields and production are derived through downscaling procedures applied to agricultural statistics of main food and cash crops for rain-fed and irrigated cultivated areas separately. Results are presented per grid-cell as (i) crop harvested area, production and yields, and (ii) aggregate crop production value.

The comparison between simulated potential yields and production with downscaled results for current observed yield and production of crops provides relevant yield and production gap information.

AEZ generates large databases of (i) natural resources endowments relevant for agricultural uses and (ii) spatially detailed results of individual LUT assessments in terms of suitability and attainable yields, (iii) spatially detailed results of current yields of main food and fiber commodities for all rain-fed and irrigated cultivated areas, and (iv) spatially detailed yield and production gaps also for main food and fiber commodities.

These databases generated in AEZ provide the agronomic backbone for various applications, including the quantification of alternative land use options under current and future climate, discussed in this report. Results are commonly aggregated for current major land use/cover patterns and by administrative units.

2.2 Overview of AEZ procedures

The AEZ methodology uses a land resources inventory to assess, for specified management conditions and levels of inputs, all feasible agricultural land-use options and to quantify anticipated production of cropping activities relevant in the specific agro-ecological context.

The suitability of land for the cultivation of a given crop/LUT depends on crop requirements as compared to the prevailing agro-climatic and agro-edaphic conditions. AEZ combines these two components by first determining agro-climatic suitabilities and then modifying the estimate according to edaphic suitabilities of location specific soil and terrain characteristics.

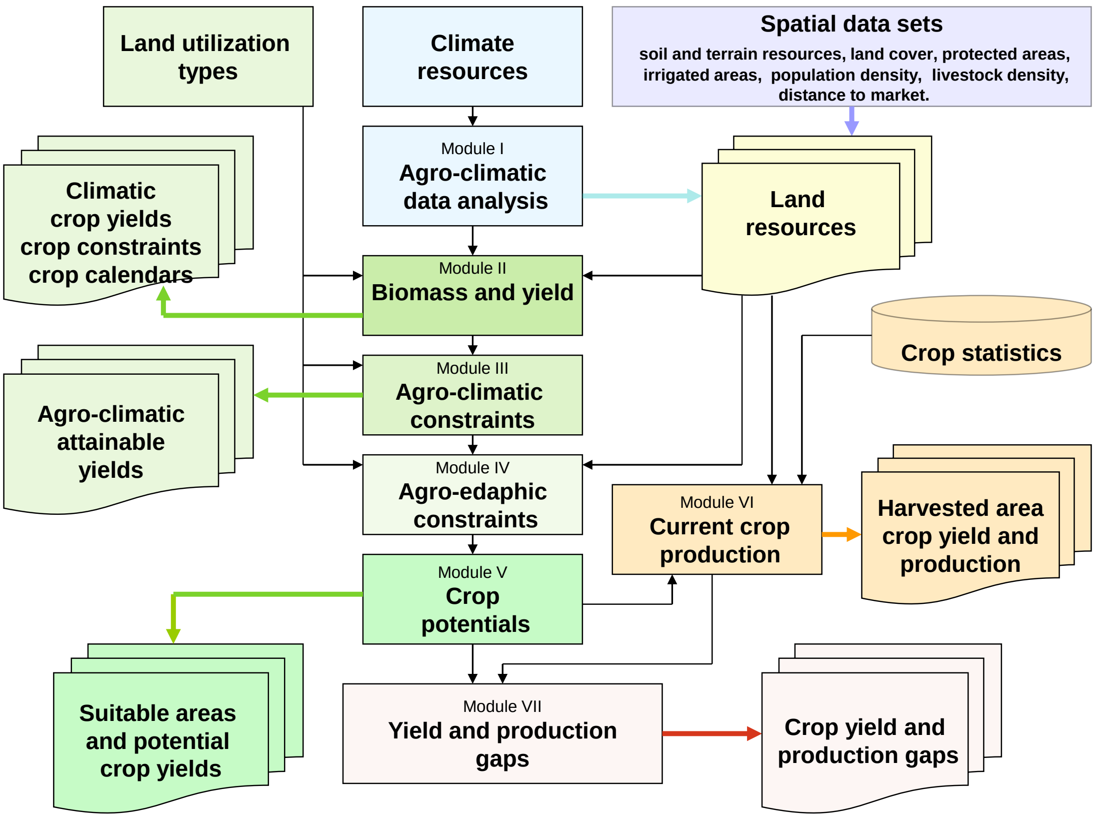


Figure 1: Overall structure of AEZ Model

The methodology allows stepwise review of results. Calculation procedures for establishing crop suitability estimates in AEZ include five main steps of data processing, namely:

(i) Module I: Climate data analysis and compilation of general agro-climatic indicators;

(ii) Module II: Crop-specific agro-climatic assessment and water-limited biomass/yield calculation;

(iii) Module III: Yield-reduction due to agro-climatic constraints;

(iv) Module IV: Edaphic assessment and yield reduction due to soil and terrain limitations; and

(v) Module V: Integration of results from Modules I-IV into crop-specific grid-cell databases of agro-ecological suitability and yields.

For obtaining grid-cell level area, yield and production of prevailing main crops, two main activities are involved, namely:

(vi) Module VI: (a) Estimation of shares of rain-fed or irrigated cultivated land, and (b) estimation of area, yield and production of the main crops in the rain-fed and irrigated cultivated land shares.

Finally, inventories of yield gaps are compiled from comparisons of potential rain-fed yields with actual yields. The activities include:

(vii) Module VII: Quantification of yield gaps between potential attainable crop yields and downscaled current crop yield statistics.

The overall AEZ model structure is schematically shown in Figure 1.

2.2.1 Module I: Agro-climatic data analysis

Module I calculates climate-related variables and indicators for each grid-cell. The module processes spatial grids of historical, base line and projected future climate to create layers of agro-climatic indicators relevant to plant production. First, available monthly climate data are read and converted to variables required for subsequent calculations. Temporal interpolations are used to transform monthly data to daily estimates required for characterization of thermal and soil moisture regimes. (Alternatively, AEZ can work with daily data.) The latter includes calculation of reference potential and actual evapotranspiration through daily soil water balances.

Thermal regime characterization generated in Module I includes thermal growing periods, accumulated temperature sums and quantification of annual temperature profiles. Soil water balance calculations determine potential and actual evapotranspiration for a reference crop, length of growing period (LGP, days) including characterization of LGP quality and begin and end dates of one or more LGPs. Based on a sub-set of these indicators, a multiple-cropping zones classification is produced for rain-fed and irrigated conditions.

2.2.2 Module II: Biomass and yield calculation

In Module II, selected land utilization types (LUT) are assessed for water-limited biomass production and yields for each of the three assumed input levels. The LUT concept defines a range of sub-types within a plant species, including differences in crop cycle length (i.e., days from sowing to harvest), growth and development parameters. Sub-types differ with assumed level of inputs. For instance, at low input level traditional crop varieties are considered, which may have different qualities that are preferred but have low yield efficiencies (harvest index) and because of management limitations are grown in relatively irregular stands with inferior leaf area index. In contrast, with high input level high-yielding varieties are deployed with advanced field management and machinery providing optimum plant densities with high leaf area index.

Module II first calculates maximum attainable biomass and yield as determined by radiation and temperature regimes, followed by the computation of respective rain-fed and irrigated crop water balances and the establishment of optimum crop calendars for each of these conditions. Crop water balances are used to estimate actual crop evapotranspiration, accumulated crop water deficit during the growth cycle (respectively irrigation water requirements for irrigated conditions), and attainable water-limited biomass and yields for rain-fed conditions. First, a window of time is determined when conditions permit LUT cultivation (e.g., prevailing LGP in each grid cell). The specific growth of each LUT is tested for the days during the permissible window of time with separate analysis for irrigated and rain-fed conditions. The growing dates and cycle length producing the highest (water-limited or irrigated) yield define the optimum crop calendar of each LUT in each grid-cell.

Results of Module II include LUT-specific temperature/radiation defined maximum yields, yield reduction factors accounting for sub-optimum thermal conditions, yield impacts due to soil water deficits, estimated amounts of soil water deficit, potential and actual LUT evapotranspiration, accumulated temperature sums during each LUT crop cycle, and optimum crop calendars.

2.2.3 Module III: Agro-climatic constraints

Module III computes for each grid cell specific multipliers, which are used to reduce yields for various agro-climatic constraints as defined in the AEZ methodology. This step is carried out in a separate module to make explicit the effect of limitations due to soil workability, pest and diseases, and other constraints and to permit time-effective reprocessing in case new or additional information is available. Four groups of agro-climatic constraints are considered for Mauritius:

a) Yield adjustment due to year-to-year variability of soil moisture supply; this factor is applied to adjust yields calculated for average climatic conditions

b) Yield losses due to the effect of pests, diseases and weed constraints on crop growth

c) Yield losses due to water stress, pest and diseases constraints on yield components and yield formation of produce (e.g., affecting quality of produce)

d) Yield losses due to soil workability constraints (e.g., excessive wetness causing difficulties for harvesting and handling of produce)

Agro-climatic constraints are expressed as yield reduction factors according to the different constraints and their severity for each crop and by level of inputs. Due to paucity of empirical data, estimates of constraint ratings have been obtained through expert opinion.
The results of Module III update for each grid cell the results of Module II by filling in the respective LUT agro-climatic constraints yield reduction factors. Results of agro-climatic suitabilities are mapped for spatial verification and further use in applications.

2.2.4 Module IV: Agro-edaphic constraints

This module evaluates crop-specific yield reduction due to limitations imposed by soil and terrain conditions. Soil suitability is determined on the basis of the soil type and attribute database derived from the information in the Soil Map of Mauritius (ORSTOM 1984). Soil nutrient availability, soil nutrient retention capacity, soil rooting conditions, soil oxygen availability, soil toxicities, soil salinity and sodicity conditions and soil management constraints are estimated on crop by crop basis and are combined in a crop and input specific normalized suitability rating factor ranging from 0 (entirely unsuitable) to 100 (no constraint for cultivation).

The soil evaluation algorithm assesses for soil types and slope classes the match between crop requirements and the respective soil qualities as derived from soil attributes.

2.2.5 Module V: Integration of climatic and edaphic evaluation

Module V executes the final step in the AEZ crop suitability and land productivity assessment. It retrieves the LUT specific results of the agro-climatic evaluation for biomass and yield calculated in Module II/III for different soil classes and it uses the edaphic rating produced for each soil/slope combination in Module IV. The inventories of soil resources and terrain-slope conditions are integrated by ranking all soil types in each soil map unit with regard to occurrence in different slope classes. Considering simultaneously the slope class distributions of all grid cells belonging to a particular soil map unit results in an overall consistent distribution of soil-terrain slope combinations by individual soil association map units and 3 arc-second grid cells. Soil and slope rules are applied separately for rain-fed and irrigated conditions.

The algorithm in Module V steps through the grid cells of the spatial soil association layer of the Mauritius Soil Database and determines for each grid cell the respective make-up of land units in terms of soil types and slope classes. Each of these component land units is separately assigned the appropriate suitability and yield values and results are accumulated for all elements. Processing of soil and slope distribution information takes place at 3 arc-second grid cells. One hundred of these produce the edaphic characterization at 30 arc-second, the resolution used for computing AEZ agro-climatic results.

Cropping activities are the most critical in causing topsoil erosion, because of their particular cover dynamics and management. The terrain-slope suitability rating used in the AEZ study accounts for the factors that influence production sustainability and is achieved through: (i) defining permissible slope ranges for cultivation of various crop/LUTs and setting maximum slope limits; (ii) for slopes within the permissible limits, accounting for likely yield reduction due to loss of fertilizer and topsoil; and (iii) distinguishing among a range of farming practices, from manual cultivation to fully mechanized cultivation. In addition, the terrain-slope suitability rating is varied according to amount and distribution of rainfall.

Application of the procedures in the modules I-V results in an expected yield and suitability distribution regarding rain-fed and irrigation conditions for each 3 arc-second grid cell (about 90 x 90 m) and each crop/LUT. Land suitability of each LUT is assessed and is described in five classes: very suitable (VS), suitable (S), moderately suitable (MS), marginally suitable (mS), very marginally suitable (VmS) and not suitable (NS). Large crop/LUT specific databases are created, which are used to calculate the extents of land with cultivation potential, tabulation of results by broad land use categories, impacts of climate change on crop production potentials, and irrigation water requirements for current and future climates.

2.3 Geographical input datasets

2.3.1 Climate data

Data of mean monthly temperatures and precipitation were extracted from the WorldClim 30 arc-second raster databases (Hijmans et al. 2005). WorldClim is a set of global climate layers (climate grids) with a spatial resolution of 30 arcsec (about one square kilometer), which was obtained by interpolations of observed data and are representative of the period 1950-2000.

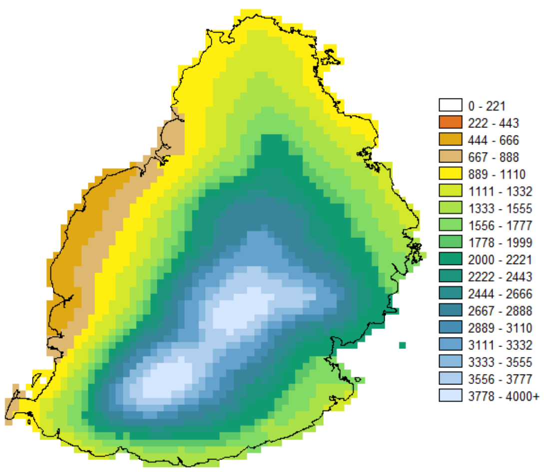


Figure 2: Mean annual rainfall (1970-2000) (30 arc-second grid cells)

For precipitation, an additional data layer was used, an Isohyetal Map of Mauritius of mean annual rainfall during 1970-2000 produced by the Meteorological Services of Mauritius. Monthly grids of precipitation were calculated using the within year WorldClim rainfall distribution of each 30 arc-second grid cell scaled to the respective value of the Isohyetal Map. Figure 2 shows a marked rainfall gradient, from 600 mm annual rainfall along a strip on the west coast of Mauritius to more than 4000 mm per year in the center of the island.

For other monthly climate variables, including cloudiness, relative humidity, wind run and wet day frequency, data was used from the Climate Research Unit (CRU) at the University of East Anglia, namely the 10 arc-minute latitude/longitude gridded average monthly climate data, version CRU CL 2.0 (New et al. 2002). Original monthly CRU 10 arc-minute climatic surfaces were interpolated to a 30 arc-second grid for Mauritius. For these variables a bilinear interpolation method was applied within ArcGIS.

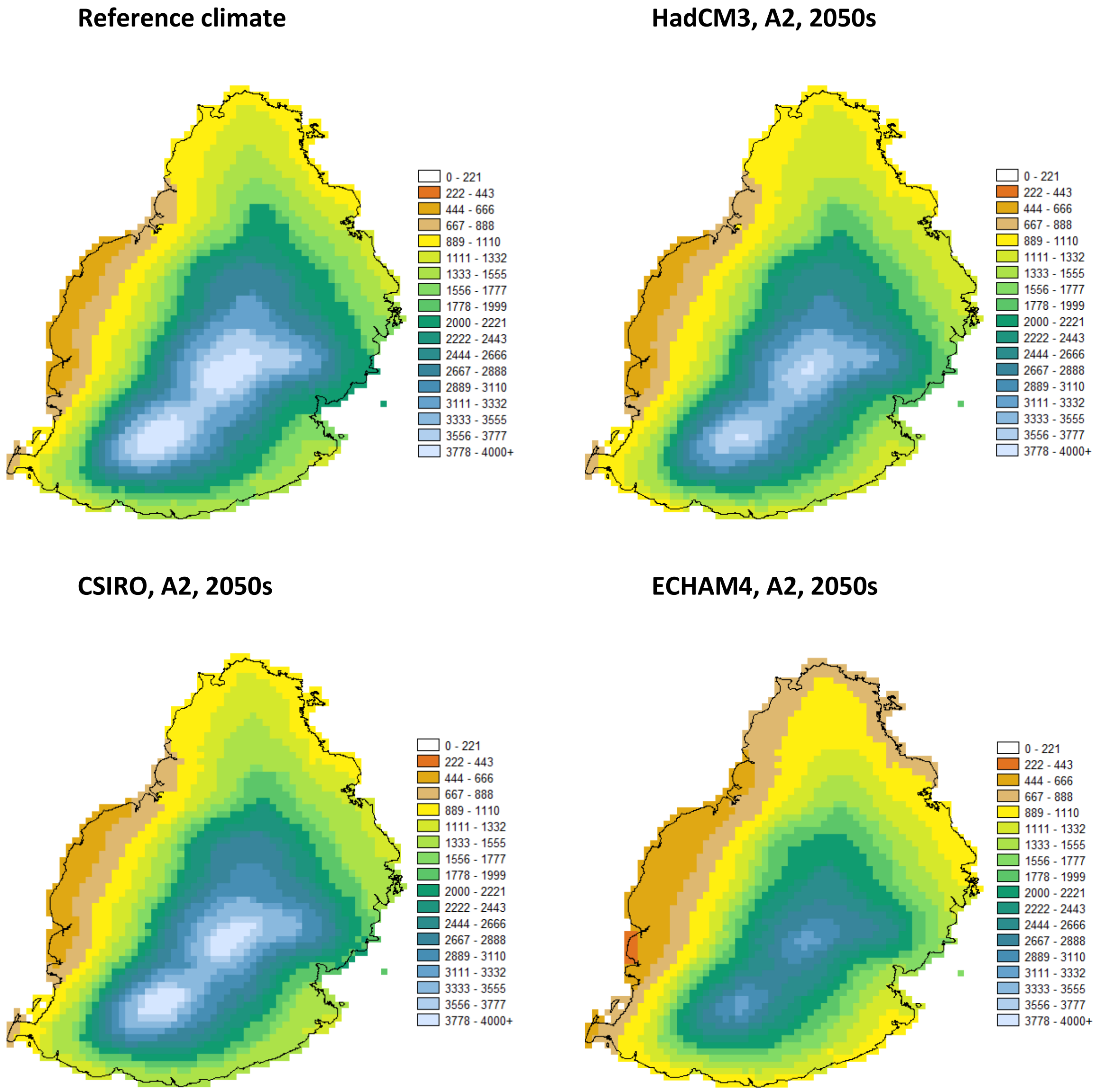


Figure 3: Mean annual rainfall, current climate and three future scenarios

Notes: **A2**: IPCC SRES A2 emission scenario; **HadCM3**: Headley Centre, UK Meteorological Office coupled climate model 3 (full scenario name: Hadley CM3 A2); **CSIRO**: Australian Commonwealth Scientific and Research Organization Mark 2 Model (full name: CSIRO Mk2 A2); **ECHAM4**: Max-Planck-Institute for Meteorology GCM model (full scenario name: MPI ECHAM4 A2)

For the analysis of climate change impacts on agricultural production potential, available climate predictions of General Circulation Models (GCM) were used for characterization of future climates. GCM model outputs for individual climate attributes were processed to calculate differences of the respective means for 30-year periods (the 2020s: years 2011-2040; the 2050s: years 2041-2070; and the 2080s: years 2071-2100) with the GCM control run climate for 1961-1990. An inverse distance weighted interpolation to a 30 arc-minute grid was performed on these 'deltas' of the centre points of each grid cell in the original GCM. The changes ('deltas') for monthly climatic variables were then applied to the observed reference climate (representing the period 1961-1990) to generate future climate data. An example showing mean annual rainfall for reference climate and three future climate projections is given in Figure 3.

Table 1 presents results of five key climate parameters for future climates in the 2050s, namely: Temperature (Tmean) precipitation (P), reference potential evapotranspiration (PET), length of growing period (LGP), P/PET ratios and net primary production (NPP) for rain-fed conditions. The AEZ analysis shows that Tmean changes are relatively minor with slight increases mainly in the order of 1.2 to 1.6 ^{o}C depending on future climate scenario and that PET increases between 1 and almost 5 percent. It also shows that P and P/PET ratios are decreasing quite considerably between 4 and 25 percent. LGPs decrease between 6 and 13 percent, although in the western and northern districts (Riviere Du Rempart, Pamplemousses, Port Louis and Black river), where rainfall is lowest because of rain-shadow effects, LGPs are decreasing more between 9 and 25 percent. Change of NPP (without considering possible CO_2 fertilization effects) varies depending on future climate scenario between about 0 and 8 percent decrease in Mauritius as a whole, the decrease in western and northern districts is however much more pronounced, namely between 4 and 27%.

Table 1: Key climate parameters by future climate scenarios for the 2050s

Mauritius, Main island	**Annual averages/totals**				**Change with respect to baseline climate (^{o}C/%)**		
	CrAv6190	**H3A22050**	**EHA22050**	**CSA22050**	**H3A22050**	**EHA22050**	**CSA22050**
Mean Annual Temperature (deg C)	22.4	23.7	23.6	24.0	1.3	1.2	1.6
Annual Precipitation (mm)	1984	1840	1519	1900	-7.3	-23.4	-4.2
Annual Potential Evapotranspiration (mm)	1374	1395	1389	1437	1.5	1.1	4.6
Number of Growing Period days (days)	325	301	282	306	-7.4	-13.2	-5.8
100*P/PET ratio (%)	147	134	111	135	-8.8	-24.5	-8.2
Net Primary Production (tons C/ha)	19.3	18.6	17.7	19.3	-3.5	-8.0	0.2

The analyses shows that towards the 2050s agro-climatic conditions for rain-fed agricultural production are deteriorating overall, but specially in the relative dry western and northern districts. In particular, future climate conditions as projected with Max-Planck-Institute for Meteorology GCM model (EHA22050) shows strong decreases in rainfall, length of growing period and, as a consequence, in net primary production and implicitly predicts for the 2050s substantial lower overall rain-fed production capacities of Mauritius.

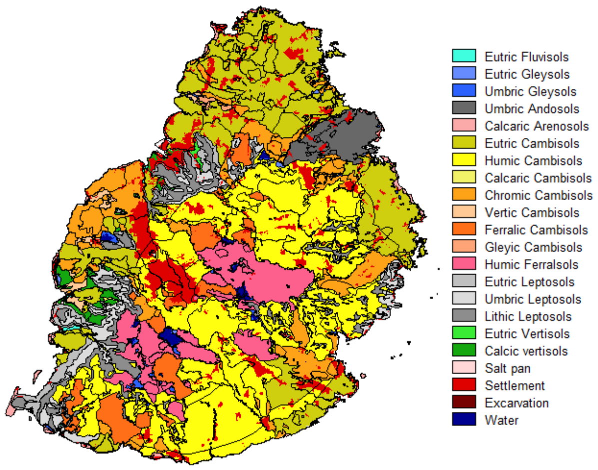
2.3.2 Soil data

Soil data used in the assessment is based on the "Carte pédologique de l'Ile de Maurice" (Maps and explanatory note by P. Willaime (ORSTOM 1984).

Mauritius is mainly from volcanic origin. The island is built up by a series of lava flows that occurred over a period between 8 to 9 million years ago and until as recent as 20.000 years ago. (*Old lavas, Early lavas, Intermediate lavas and Late lavas).* The lavas are alternated with pyro-clastic ashes deposits. Pedogenetic development of these mainly volcanic deposits is dominated by the age of the deposits and local rainfall regimes. The soils of Mauritius have been classified according to the French CPSC system (Commission de Pedologie et de Cartography des Sols).

This soil map of Mauritius comprises six main soil groups:

- Sols Mineraux Bruts (A,B,C)
- Sols Peu evolues (D)
- Vertisols (E,F)
- Sols Brunifies (F)
- Sols Ferrallitiques (F,G,H,I,J,K,L,M,N,O)
- Sols Hydromorphes (P)



The soil map is supplemented by soil profile analysis data, covering all soils of agricultural relevance. The soil profile data provides for a varying number of depth layers, data on texture, organic material, pH and nutrient absorption complexes. The locations of the available 250 soil profiles are associated with the 1175 individual soil map polygons. Completeness of soil information from the soil profile data varies between locations and by soil profile horizons.

Figure 4: Soil Map of Mauritius (FAO'90 dominant soils)

For obtaining a complete soil attribute database covering all soil map polygons and all soil units, the following activities were employed:

(i) Cartographic information available from the soil map of Mauritius was used to subdivide association map units (by including specific map overprint information) where applicable. The soil profile data was normalized in topsoil (0-30 cm) and subsoil (30-100 cm) layers, to make it compatible with the Harmonized World Soil Database (Nachtergaele et al. 2009), and the descriptions of all 70 legend units were merged with standardized soil profile data. Further, soil map polygons have been characterized for land use cover characteristics and terrain slope conditions;

(ii) On the basis of published soil correlation tables between CPCS and FAO '90 revised soil legend, available soil profile parameters and soil legend descriptions, supplemented with information on present land use and terrain sloping conditions each (revised) polygon of the soil map of Mauritius was correlated with the FAO'90 soil classification system (see Figure 4);

(iii) From information contained in the map unit descriptions, the actual use of the land and terrain slope data, occurrences of gravel, stoniness, depth of lithic contact and prevalence of "meules" (piles of stones) were interpreted in terms of FAO'90 compatible soil phase information; and

(iv) Finally, the correlation with the FAO 90 soil unit classification was used for linking the Mauritius soil profile data with data of an international reference soil profile database (Version 2.0 of the WISE). The WISE data was subsequently used to fill data gaps in soil profile database of Mauritius and also to expand it with additional relevant soil characteristics.

The above procedures and the creation of an AEZ compatible soil attribute database enabled the use of the AEZ agro-edaphic crop suitability evaluation for the soil inventory of Mauritius.

For the agro-edaphic assessment in AEZ-Mauritius, soil attributes have been organized as described for the Harmonized World Soil Database (HWSD, Version 1.1, March 2009). A detailed description is available at: www.iiasa.ac.at/Research/LUC/luc07/External-World-soil-database/HTML/index.html.

Soil mapping units are characterized in terms of selected soil parameters (organic carbon, pH, soil water holding capacity, soil depth, cation exchange capacity of the soil and the clay fraction, total exchangeable nutrients, lime and gypsum contents, sodium exchange percentage, salinity, textural class and granulometry). In addition, the FAO system used in HWSD includes occurrences of soil phases (FAO'90) and specific "other soil characteristics", such as vertic soil properties, which may affect agricultural land use.

Materials used for Mauritius soil inventory:

1. CPCS. 1967 Classification des sols Grignon, France, Ecole nationale superieure agronomique. 87 pp.
2. 1:50,000 Soil map of Mauritius (Ile de Maurice, Carte Pédologique) 1983 (hard copy and digital version).
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2.3.3 Elevation data and derived terrain slope data

A global terrain slope database has been compiled using elevation data (Figure 5) from the Shuttle Radar Topography Mission (SRTM). The SRTM data (Version 4) is available as 3 arc-second DEMs (Jarvis et al. 2008). Data tiles covering Mauritius were obtained from CIAT-CIS (website http://srtm.csi.cgiar.org) and processed to align with other data layers of Mauritius.

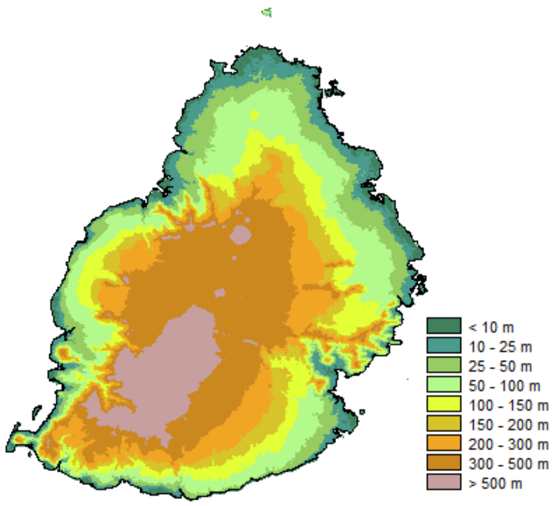

Figure 5: Elevation (3 arc-second grid)

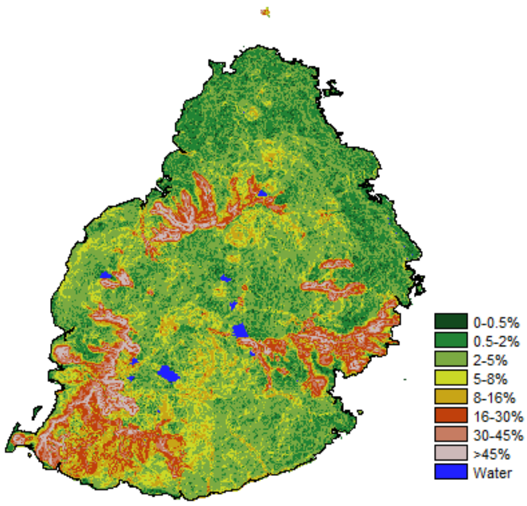

Figure 6: Terrain slope classes (3 arc-second grid)

High resolution SRTM data has been used for calculating: (i) terrain slope gradients and classes (for each 3 arc-sec grid cell); (ii) aspect of terrain slopes (for each 3 arc-sec grid cell); and (iii) distributions of slope gradient classes for each 30 arc-second grid. Slope distributions are stored in terms of eight slope gradient classes used in the AEZ terrain suitability assessment: 0–0.5%, 0.5–2%, 2–5%, 5–8%, 8–16%, 16–30%, 30–45%, and >45%. A map of slope classes is shown in Figure 6.

2.3.4 Land cover data

According to the GIS data base used in this study, Mauritius has a total land surface area of 186,540 ha. The cultivated land is 99,580 ha, or 53 percent of the total area of the island. Around 8 percent is occupied by built-up areas. The remaining land consists of forests (11%), scrub land, grassland, woodland (27%), and reservoirs and other inland water (0.6%).

For use in AEZ-Mauritius, three available GIS layers were combined, containing respectively information on (i) major land use/cover, (ii) irrigated areas, and (iii) inland water bodies. The resulting six land use/land cover categories, used for land accounting and to characterize each 3 arc-second grid-cell, are: (1) irrigated cultivated land; (2) rain-fed cultivated land; (3) forest land; (4) scrub and other vegetated land; (5) settlements; and (6) water bodies (see Figure7; Table 2).

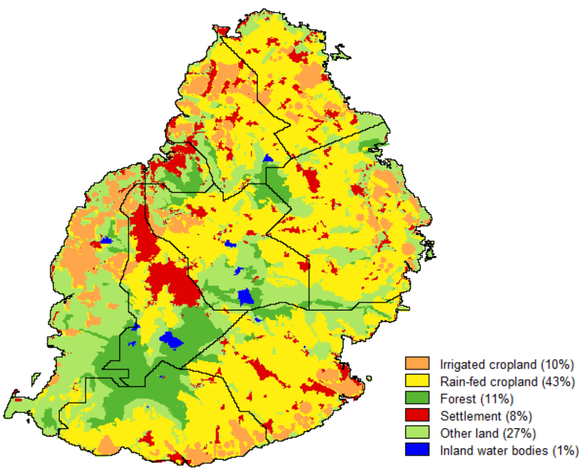

Figure 7: Major land use/land cover classes (3 arc-second grid cells)

Table 2: Shares of major land use/cover classes by district

	Cultivated land			Forest (%)	Other land (%)	Settlement (%)	Inland water bodies (%)	Total land (000 ha)
	Total (%)	Rain-fed (%)	Irrigated (%)					
Riviere Du Rempart	73	60	13	0	18	9	0	17.2
Pamplemousses	65	46	18	3	21	10	1	17.7
Flacq	63	56	7	5	26	6	0	31.7
Port Louis	3	3	0	24	43	30	0	4.0
Black River	30	7	23	10	58	2	0	24.6
Plaines Wilhelms	26	23	3	31	18	23	2	18.5
Moka	48	43	5	11	34	5	2	23.0
Grand Port	70	62	7	5	17	8	0	25.9
Savanne	60	50	10	20	17	3	0	23.0
Mauritius	53	43	10	11	27	8	1	185.6

2.4 Agricultural statistics

In the four decades since 1961 the harvested area in Mauritius declined gradually from 91,000 hectares to 82,000 hectares in 2000. After 2000 there was a more rapid decline leaving about 69,000 hectares harvested in 2010.

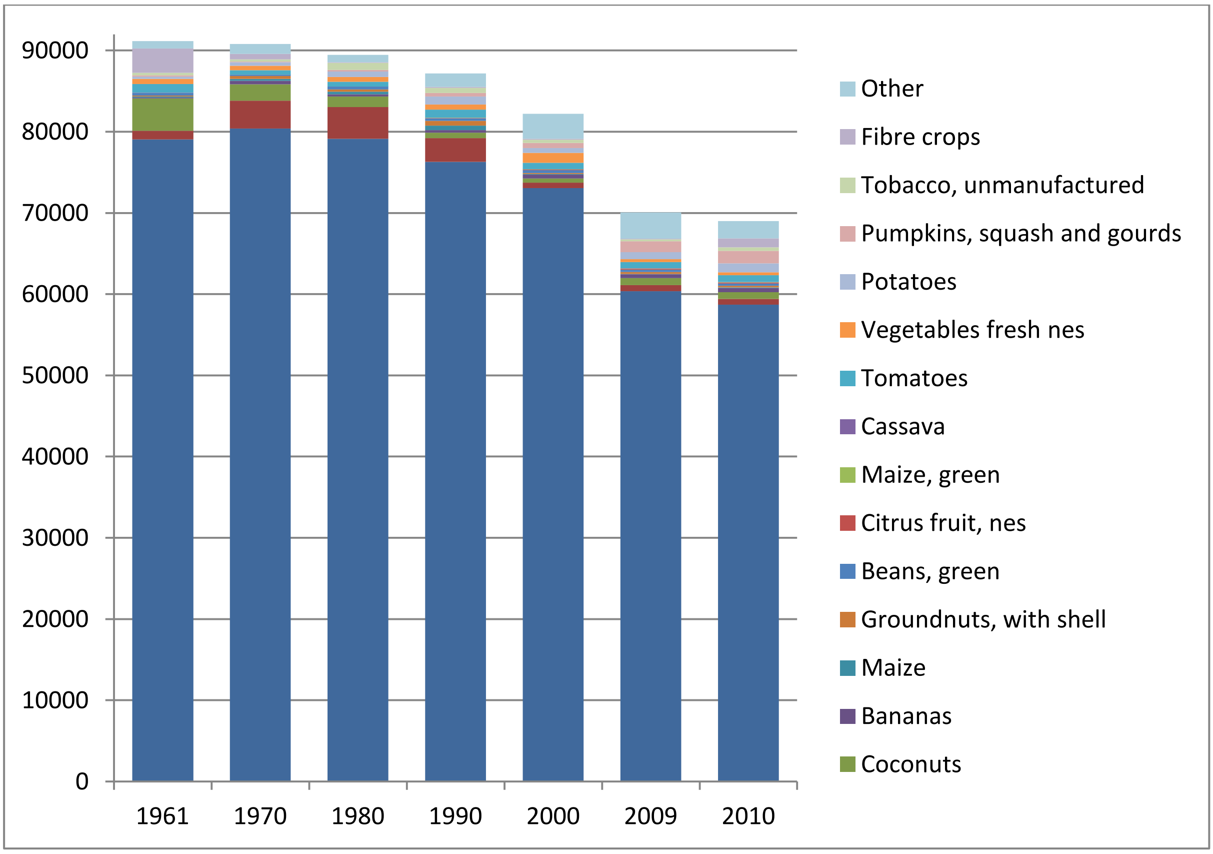

Figure 8: Harvested areas by crop, selected years 1961-2010 (Source: FAOSTAT)

The harvested area of sugarcane alone reduced by a quarter from 79,000 ha to about 59,000 hectares in 2010, i.e., an average decline of more than 2000 hectares per year in the last 10 years[1]. Main causes for the decline in harvested areas of sugarcane have been real estate development (incl. urban expansion at the borders of settlements and along main roads often on high quality sugarcane land) and crop diversification. Important drivers, apart from economic considerations, were also adverse climatic conditions in recent years. Some remote, marginal small scale sugar areas were left fallow, and subsequently abandoned and converted back to grass and scrub land. Figure 8 presents the development of harvested areas for main crops in Mauritius since 1961.

Table 3: Agriculture statistics of Mauritius

Area harvested (ha)

	1980	1990	2000	2009	2009/1980
Sugarcane	79,128	76,303	73,056	60,503	76%
Banana	255	350	489	494	194%
Coconut	1,300	650	500	882	68%
Tea	3,915	2,905	670	713	18%
Bean, green	325	319	351	281	86%
Maize	326	542	70	101	31%
Groundnut, with shell	288	592	123	241	84%
Citrus fruit, nes	n.a.	35	98	132	n.a.
Maize, green	n.a.	17	27	49	n.a.
Cassava	5	14	10	27	540%

Yield (t/ha)

	1980	1990	2000	2009	2009/1980
Sugarcane	58	73	70	77	134%
Banana	10	18	17	22	215%
Coconut	4	4	3	3	65%
Tea	1	2	2	2	185%
Bean, green	3	4	5	5	140%
Maize	2	4	9	8	370%
Groundnut, with shell	4	3	3	2	65%
Citrus fruit, nes	n.a.	4	4	3	n.a.
Maize, green	n.a.	6	7	8	n.a.
Cassava	17	14	15	15	86%

Production Quantity (t)

	1980	1990	2000	2009	2009/1980
Sugarcane	4,564,400	5,548,290	5,109,500	4,669,420	102%
Banana	2,625	6,135	8,500	10,920	416%
Coconut	5,000	2,300	1,500	2,216	44%
Tea	4,386	5,751	1,312	1,481	34%
Bean, green	1,123	1,235	1,708	1,355	121%
Maize	732	2,265	623	839	115%
Groundnut, with shell	1,071	1,755	408	587	55%
Citrus fruit, nes	n.a.	150	410	406	n.a.
Maize, green	n.a.	110	194	402	n.a.
Cassava	86	190	151	400	465%

Source: FAOSTAT

[1] The sugar industry of Mauritius is nevertheless fairly optimistic, although some further decline of harvested area of sugarcane is expected. Main income prospects come from molasses used for electricity generation and from the real estate markets and within the agricultural sector from crop diversification in which in particular potato and flower production seem promising. Estates are preparing for ethanol production and are awaiting national level policy decisions on biofuels.

Table 3 provides a historical overview of harvested areas, yield and production for the top ten agricultural commodities of Mauritius (ranked according to 2009 production). As for production, the substantial decline of harvested areas has been compensated by substantial yield increases, in particular sustained by a 34% yield increase of sugarcane since the early 1980s.

2.5 Biomass and yield calculation

The main purpose of AEZ Module II is the calculation of agro-climatically attainable biomass and yield for specific land utilization types (LUTs) under various input/management levels for rain-fed and irrigated conditions separately.

Module II consists of two steps:

(i) Calculation of crop biomass and yield potentials considering only prevailing radiation and temperature conditions; and

(ii) Computation of yield losses due to water stress during the crop growth cycle. The estimation is based on rain-fed crop water balances for different levels of soil water holding capacity. Yield estimation for irrigation conditions assumes that no crop water deficits will occur during the crop growth cycle.

2.5.1 Land Utilization Types

Differences in crop types and production systems are empirically characterized by the concept of Land Utilization Types (LUTs). A LUT consists of a set of technical specifications for crop production within a given socioeconomic setting. Attributes specific to a particular LUT include agronomic information, nature of main produce, water supply type, cultivation practices, utilization of produce, and associated crop residues and by-products. The GAEZ v3.0 framework distinguishes nearly 900 crop/LUT and management combinations, which are separately assessed for rain-fed and irrigated conditions. These LUTs are made-up of 49 different food, feed, fiber, and bio-energy crops. The calculated yield of each crop/LUT depends on climate, water sources and the assumed intensity of inputs and management. Three generic levels of input/management conditions are defined: low, intermediate, and high input level.

Under a low level of inputs (traditional management assumption), the farming system is largely subsistence based. Production is based on the use of traditional cultivars (if improved cultivars are used, they are treated in the same way as local cultivars), labor intensive techniques, and no application of nutrients, no use of chemicals for pest and disease control and minimum conservation measures.

Under a high level of input (advanced management assumption), the farming system is mainly market oriented. Commercial production is a management objective. Production is based on improved or high yielding varieties, is fully mechanized with low labor intensity and uses optimum applications of nutrients and chemical pest, disease and weed control.

This variety in management and input levels is translated into yield differences by assigning different parameters for LUTs depending on the input/management level, e.g., such as harvest index and maximum leaf area index. LUTs are parameterized to reflect environmental and eco-physiological requirements for growth and development of different crop types. Numerical values of crop parameters are varied depending on the assumed input/management level to which LUTs are subjected.

2.5.2 Biomass and yield calculation.

As initial criteria to screen the suitability of grid-cells for the possible presence of individual LUTs, GAEZ tests the match of prevailing conditions with the LUT’s temperature requirements.

Matching is tested for the full range of possible starting dates and resulting in optimum match, sub-optimum match and not suitable conditions. The "optimum and suboptimum match categories" are considered for further biomass and yield calculations.

Calculation procedures of constraint-free biomass and yield (i.e., carbon accumulation driven mainly by prevailing radiation and temperature regimes in a grid-cell) are based on a robust eco-physiological model (Kassam, 1977).

The constraint-free crop yields calculated in AEZ reflect yield potentials with regard to temperature and radiation regimes prevailing in the respective grid-cells. The model requires the following crop characteristics: (a) Length of growth cycle (days from emergence to full maturity); (b) minimum temperature requirements for emergence; (c) maximum rate of photosynthesis, (d) respiration rates for leguminous and non leguminous crops as functions of temperature; (e) length of yield formation period; (f) leaf area index (LAI) at maximum growth rate; (g) harvest index (Hi); (h) crop adaptability group, and (i) sensitivity of crop growth cycle length to heat provision. The biomass calculation also includes simple procedures to account for different levels of atmospheric CO2 concentrations.

For each crop type and grid-cell the starting and ending dates of the crop growth cycle are determined optimally to obtain best crop yields, separately for rain-fed and irrigated conditions. This procedure also entails adaptation of crop calendars ('smart farmer') in simulations with year-by-year historical weather conditions, or under climate distortions applied in accordance with various climate change scenarios.

2.5.3 Water limited biomass production and yields

Under rain-fed conditions, water stress may occur during different stages of the crop development reducing biomass production and the yields achieved. In AEZ, water requirements for each LUT are calculated and taken into account in the calculation of LUT-specific water balance and actual evapotranspiration in a grid-cell.

The total water requirement of a crop without any water stress is assumed to be the crop-specific potential evapotranspiration (ETm). ETm is calculated in proportion to reference potential evapotranspiration (ETo), as in Module I, multiplied by crop and crop-stage specific parameters 'kc'. The values of kc for different stages of crop development are given as input parameters (FAO 1992a, 1992b, 1992c, 1998).

Yield reduction in response to water deficits is calculated as a function of the relationship between actual crop evapotranspiration (∑ETa, mm/day) and maximum crop evapotranspiration (∑ETm, mm/day), both accumulated within and across the four crop stages. The sensitivity of each crop to water stress is expressed by the value of the water stress coefficient (ky, fractional), a LUT-specific parameter which changes with crop development stage. Water limited yield is then calculated as potential yield multiplied by the grid-cell specific water-stress reduction factor (FAO 1992b, 1998).

2.5.4 Agro-climatic yield-constraints

At the stage of computing potential biomass and yields, no account is taken of the climatic–related effects operating through pests and diseases, and workability.

Agro-climatic constraints cause direct or indirect losses in the yield and quality of produce. Yields losses in a rain-fed crop due to agro-climatic constraints have been formulated based on principles and procedures originally proposed in FAO (1978-81a,b) and on experiences in individual countries (e.g., China, Bangladesh, Mozambique, Ghana, Kenya).

The relationships between these constraints with general agro-climatic conditions such as moisture stress and excess air humidity are varying by location, between agricultural activities as well as by the use of control measures. The impact of these yield constrains on the basis of prevailing climatic conditions has been approximated. The efficacy of control of these constraints (e.g., pest management) is accounted for through the assumed three levels of inputs. Due to the relatively high level of uncertainty, the assessment of agro-climatic constraints has been applied separately in Module III, such that effects are transparent, well separated and AEZ assessments can be made with and without these constraints.

Five different yield constrains (i.e., yield-reducing factors) are taken into account: (a) Long-term limitation to crop performance due to year-to-year rainfall variability; (b) Pests, diseases and weeds damage on plant growth; (c) Pests, diseases and weeds damage on quality of produce; (d) Climatic factors affecting the efficiency of farming operations; and (e) Frost hazards (not applicable).

2.6 Agro-edaphic suitability

Module IV estimates factors for yield reductions caused by constraints due to prevailing soil and terrain-slope conditions. The soil suitability is assessed through crop/LUT specific evaluations of seven major soil qualities. Terrain suitability is estimated from terrain-slope and rainfall concentration characteristics. Soil and terrain characteristics are read from 3 arc-second grid-cells in which prevailing soil and terrain combinations have been quantified. Soil units are characterized by the following soil parameters: Organic carbon, pH, water storage capacity, soil depth, cation exchange capacity of the soil and the clay fraction, total exchangeable nutrients, lime and gypsum contents, sodium exchange percentage, salinity, textural class and granulometry. For this AEZ-Mauritius study, the calculations are crop/LUT specific and are performed for an assumed high input level and four water supply systems separately, including rain-fed conditions, sprinkler irrigation, gravity irrigation and drip irrigation.

2.6.1 Soil suitability assessment procedures

In the AEZ approach, edaphic suitability is assessed in terms of several land qualities specifically related to soil properties and conditions as reflected in the Mauritius Soil Database and the AEZ terrain-slope database.

The individual soil profile attributes, soil drainage conditions and prevalence of soil phases that have been related to requirements and tolerances of crops need to be combined ultimately into land utilization specific soil suitability ratings. First, individual soil qualities are defined and quantified. Table 4 below provides an overview of the seven soil qualities used in AEZ in relation to relevant soil profile attributes, including soil drainage conditions and soil phase prevalence.

Table 4: Soil qualities and soil attributes

Soil Qualities		Soil quality related soil profile attributes, soil drainage conditions and soil phase characteristics
SQ1	Nutrient availability.	Soil texture, soil organic carbon, soil pH, total exchangeable bases.
SQ2	Nutrient retention capacity.	Soil texture, base saturation, cation exchange capacity of soil and of clay fraction.
SQ3	Rooting conditions.	Soil textures, coarse fragments, vertic soil properties and soil phases affecting root penetration and soil depth and soil volume.
SQ4	Oxygen availability to roots.	Soil drainage and soil phases affecting soil drainage
SQ5	Excess salts.	Soil salinity, soil sodicity and soil phases influencing soil salinity and sodicity conditions.
SQ6	Toxicity.	Calcium carbonate and gypsum.
SQ7	Workability (constraining field management).	Soil texture, effective soil depth/volume, and soil phases constraining soil management (soil depth, rock outcrop, stoniness, gravel/concretions and hardpans).

The seven soil qualities (SQ1-7) are estimated from soil characteristics (e.g., organic carbon content, soil pH, texture) read from the Harmonized World Soil Database. The soil qualities influencing crop performance considered in the assessment include: nutrient availability (SQ1); nutrient retention capacity (SQ2); rooting conditions (SQ3); oxygen availability to roots (SQ4); toxicities (SQ5); salinity and sodicity (SQ6), and workability (SQ7). Each of the seven SQ ratings is derived from specific soil characteristics.

Soil profile attributes considered for both top-soil (0-30 cm) and sub-soil (30-100cm) separately include: soil texture; organic carbon content; pH, cation exchange capacity of soil and clay fraction; base saturation; total exchangeable bases; calcium carbonate contents; gypsum content; sodicity and salinity. In addition prevalence of soil phases, soil drainage characteristics, and of vertic soil properties are considered.

2.6.2 Soil suitability

Soil suitability classification procedures, follow a two-step approach:

1) Crop responses to individual soil attribute conditions and relevant soil drainage and phase conditions are combined into soil quality (SQ) ratings.
2) Soil qualities are combined in crop specific, input and management level specific and water supply specific soil suitability ratings.

Functional relationships of soil qualities have been formulated to quantify crop/LUT suitability of soil units. The following guiding principles formed the basis for the way soil qualities were combined for different levels of inputs and management:

- Nutrient availability and nutrient retention capacity are key soil qualities;
- Nutrient availability is of utmost importance for low level input farming; nutrient retention capacity is most important for high level inputs;
- Nutrient availability and nutrient retention capacity are considered of equal importance for intermediate level inputs farming;
- Nutrient availability and nutrient retention capacity are strongly related to rooting depth and soil volume available; and
- Oxygen available to roots, excess salts, toxicity and workability are regarded as equally important soil qualities, and the combination of these four soil qualities is best achieved by multiplication of the most limiting rating with the average of the ratings of the remaining three soil qualities.

The results of the soil unit suitability assessment have are stored by each soil unit/slope class/crop/input level/water supply system combination for integration with the results of the agro-climatic suitability assessment (in Module V).

2.6.3 Terrain suitability

The influence of topography on agricultural land use is manifold. Farming practices are by necessity adapted to terrain slope, slope aspect, slope configuration and micro-relief. For instance, steep irregular slopes are not practical for mechanized cultivation, while these slopes might very well be cultivated with adapted machinery and hand tools.

Sustainable agricultural production on sloping land is foremost concerned with the prevention of erosion of topsoil and decline of fertility. Usually this is achieved by combining special crop management and soil conservation measures. Cultivated sloping land may provide inadequate soil protection and without sufficient soil conservation measures, cause a considerable risk of accelerated soil erosion. In the short term, cultivation of slopes might lead to yield reductions due to loss of applied fertilizer and fertile topsoil. In the long term, this will result in losses of land productivity due to truncation of the soil profile and consequently reduction of natural soil fertility and of available soil moisture.

The terrain-slope suitability rating used in the AEZ study captures the factors described above which influence production and sustainability. This is achieved through: (i) defining for the various crops permissible slope ranges for cultivation, by setting maximum slope limits; (ii) for slopes within the permissible limits, accounting for likely yield reduction due to loss of fertilizer and topsoil, and (iii) distinguishing among farming practices ranging from manual cultivation to fully mechanized cultivation.

Slope ratings are defined by crop group, input level and for the eight slope range classes used in the land resources database (see Section 2.3.3). The combined results of soil and terrain suitability assessment can be mapped as shown in Figure 9 for sugarcane.

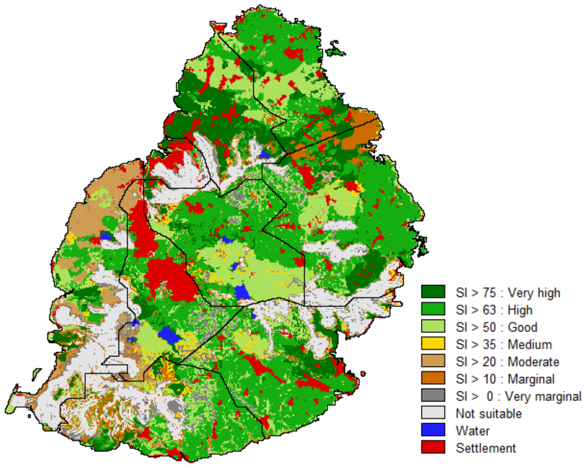

Figure 9: Edaphic (soil and terrain) suitability of rain-fed sugarcane

2.7 Integration of climatic and edaphic evaluation

Module V executes the final step in the GAEZ crop suitability and land productivity assessment. It reads the LUT specific results of the agro-climatic evaluation for biomass and yield calculated in Module II/III for different soil classes and it uses the edaphic ratings produced for each soil/slope combination in Module IV. The inventories of soil resources and terrain-slope conditions are integrated by ranking all soil types in each soil map unit with regard to occurrence in different slope classes. Considering simultaneously for all grid cells belonging to a particular soil map unit the respective slope class distribution results in an overall consistent distribution of soil-terrain slope combinations by individual soil association map units and 3 arc-sec grid cells. Soil evaluation and slope rules are applied separately for each water supply system.

The algorithm in Module V steps through the grid cells of the spatial soil association layer of the Mauritius Soil Database and determines for each grid cell the respective make-up of land units in terms of soil types and slope classes. Each of these component land units is separately assigned the appropriate suitability and yield values and results are accumulated for all elements. Processing of soil and slope distribution information takes place at 3 arc-second grid cells.

The main purpose of Module V is to compile a grid-cell database for each crop or crop group storing evaluation results that summarize the processed sub-grid information. Computations include the following steps:

- Reading agro-climatic yields calculated for separate crop water balances of six broad soil AWC classes (from Module II/III);
- Applying AEZ rules for water-collecting sites (defined as Fluvisols and Gleysols in flat terrain);
- Applying reduction factors due to edaphic evaluation for the specific combinations of soil types/slope classes making up a grid-cell; and

- Aggregating results over component land units (i.e., soil type/slope combinations).

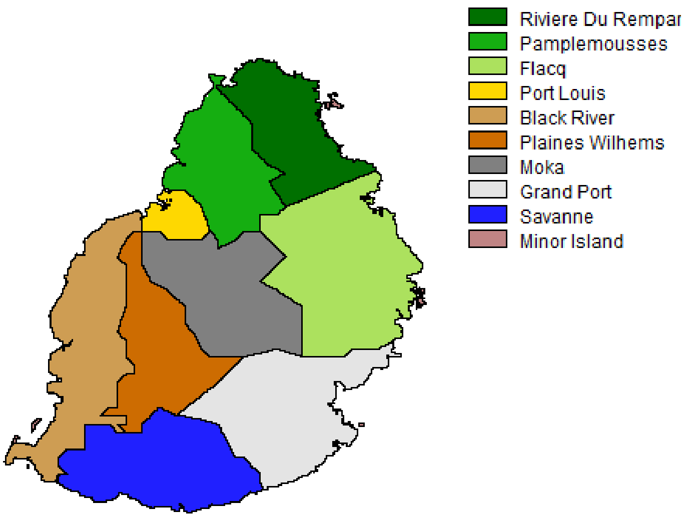

Figure 10: Administrative units used in the AEZ-Mauritius study (Source: GAUL, FAO)

The results of crop evaluations in Module V are stored as separate databases each organized by grid cells. Separate files are generated by crop, input level, water supply system and scenario/time period. Each database contains information in terms of suitable extents and potential production by suitability classes.

Various utility programs have been developed to aggregate and tabulate results by administrative units or to map the contents of Module V crop databases in terms of suitability index and potential grid cell output. A map of administrative units used in this AEZ-Mauritius study is shown in Figure 10.

3 Results

The AEZ assessments have been carried out for (i) all land within Mauritius, (ii) for rain-fed cultivated land, and (iii) for land equipped with irrigation facilities. The latter is referred to as irrigated cultivated land. Especially the rain-fed part of the cultivated land has been declining in recent years. For this assessment however, to make land comparisons over time easy and transparent, the extents and distribution of agricultural land were fixed according to the available GIS layer and the following extents of the main island have been used:

Total land	**185,570 ha**
Cultivated land*	99,580 ha
Rain-fed cultivated land	80,120 ha
Irrigated cultivated land	19,460 ha
Forest land	19,650 ha
Shrubs, grassland and woodland	50,050 ha
Built-up land	15,190 ha
Inland water	1,100 ha

*Part of the mapped cultivated land is currently not anymore in production, due to urbanization and because of abandonment of marginal agricultural land.

This section presents a selection of results of the AEZ assessment, namely: (i) suitability and attainable crop yields under reference climatic conditions, (ii) climate change impacts on crop suitability; (iii) climate change impacts on irrigation water requirements, and (iv) bio-energy feedstock potentials under reference climate and climate change conditions.

3.1 Crop suitability and attainable yields

More than 80% of the land resources of Mauritius are suitable for crop production. The remaining ca. 20% of land is not suitable due to poor soil conditions (i.e., shallow soils and/or soils with abundant stones and rocks) and/or steep terrain slopes. This relatively large fraction of suitable land is in part the result of large-scale land improvement in the past for the expansion of sugarcane. In this process, fields have been cleared from stones, concretions and rocks. Numerous piles can be seen around fields (these are referred to as “meules”) of which frequency of occurrences are indicated in the soil map of Mauritius.

Agro-ecological suitability varies substantially among individual crops. Crops have different climate, soil and terrain requirements and tolerances, posing different constraints for suitability, yields and production. Table 5 presents results for three broad classes of current land use/cover, namely for all land, for cultivated land, and for the remaining land, excluding cultivated land, land under forest, and land mapped as settlements and infrastructure. This means the remaining land mainly comprises of shrubland, grassland or woodland. For the main crops and bio-energy feedstocks extents were qualified as *prime land*, including the very suitable (VS) land, *good land* including suitable (S) and moderately suitable land (MS) and poor land including marginally suitable (mS) land, very marginally suitable (VmS) land and not suitable (NS) land.

Table 5: Crop Suitability

Crop/commodity	Suitability of all land (185,570 ha)			Suitability of cultivated land (99,580 ha)			Suitability of grassland, shrubland and woodland (50,050 ha)		
	Prime land (000ha)	Good land (000ha)	Poor land (000ha)	Prime land (000ha)	Good land (000ha)	Poor land (000ha)	Prime land (000ha)	Good land (000ha)	Poor land (000ha)
Sugarcane	45.3	62.3	78.0	31.5	40.9	27.2	6.5	10.4	33.1
Maize	13.8	38.8	133.0	9.0	26.8	63.7	2.8	6.9	40.3
Soybean	24.3	71.5	89.8	18.4	46.3	34.9	3.0	13.0	34.0
Groundnut	1.6	76.9	107.1	1.2	52.8	45.6	0.3	12.9	36.9
Banana	20.2	71.3	94.0	14.4	48.9	36.4	2.2	10.3	37.5
Coconut	0.8	20.2	164.6	0.6	14.6	84.4	0.1	3.7	46.2
Citrus	40.4	61.3	83.9	29.7	39.9	29.9	5.5	10.4	34.1
Cassava	9.0	102.8	73.8	4.2	71.2	24.2	3.2	14.6	32.2
Jatropha	35.6	47.8	102.1	26.6	27.8	45.1	4.6	10.2	35.3
Miscanthus	15.9	82.1	87.6	12.7	53.1	337.6	2.1	13.8	34.1

Results of the AEZ analysis presented here include a selection of main crops and bio-energy feedstocks, namely: sugarcane, maize, soybean, groundnut, banana, coconut, citrus, cassava, jatropha and miscanthus. Among crops assessed, the extent of prime land for sugarcane is largest; about 45,300 ha in all land, 31,500 ha in cultivated land, but only 6,500 ha in unused shrub land, grassland and woodland. This indicates that of all crops assessed, sugarcane is ecologically best adapted in Mauritius. This is in contrast to coconut of which extents of prime land under current climatic conditions is very small (<1%). Other crops/feedstocks assessed are to some degree suitable in about 80% of Mauritius.

For the estimation of crop/feedstock yields and production potentials for rain-fed production systems, high levels of inputs and management were assumed. Table 6 presents the area, yield and production potentials of rain-fed production for respectively *prime land* and *good land* in currently cultivated land. Table 7 shows the respective potentials for *prime land* and *good land* in shrubland, grassland and woodland.

Table 6: Rain-fed yield and production potentials[2] of cultivated land areas

Crop/commodity	Cultivated land (99,580 ha)					
	Prime land			Good land		
	Area (000 ha)	Yield (kg/ha)	Production (000t)	Area (000 ha)	Yield (kg/ha)	Production (000t)
Sugarcane	31.5	11,575	328.3	40.9	7,676	282.5
Maize	9.0	10,356	84.3	26.8	6,517	157.4
Soybean	18.4	4,210	69.7	46.3	2,791	116.3
Groundnut	1.2	3,144	3.3	52.8	2,177	103.5
Banana	14.4	8,231	106.4	48.9	5,668	249.2
Coconut	0.6	4,567	2.8	14.6	2,871	41.8
Citrus	29.7	4,824	143.5	39.9	3,108	124.0
Cassava	4.2	9,808	36.9	71.2	6,610	423.5
Jatropha	26.6	3,659	97.5	27.8	2,191	61.0
Miscanthus	12.7	28,880	366.7	53.1	19,662	104.4

Table 7: Rain-fed yield and production potentials[2] of shrub land, grassland and woodland areas

Crop/commodity	Shrubland, grassland and woodland (50,050 ha)					
	Prime land			Good land		
	Area (000 ha)	Yield (kg/ha)	Production (000t)	Area (000 ha)	Yield (kg/ha)	Production (000t)
Sugarcane	6.5	11,303	66.3	10.4	7,567	71.1
Maize	2.8	10,421	26.4	6.9	6,989	43.6
Soybean	3.0	4,215	11.5	13.0	2,691	31.5
Groundnut	0.3	3,159	0.8	12.9	2,069	24.1
Banana	2.2	8,146	16.4	10.3	6,090	56.6
Coconut	0.1	4,573	0.6	3.7	2,945	10.9
Citrus	5.5	4,861	26.7	10.4	3,124	32.5
Cassava	3.2	9,696	28.1	14.6	6,624	87.2
Jatropha	4.6	3,653	16.7	10.2	2,136	21.7
Miscanthus	2.1	28,220	59.3	13.8	18,713	25.9

Figure 11 presents maps of suitability distributions for each of the assessed crops. To visualize suitability of grid-cells, a crop suitability index (SI)[3] is used. The SI varies between 0 and 100; SI=0 representing unsuitable conditions, while SI=100 represents very suitable conditions in the entire grid-cell.

[2] Sugarcane yield relates to sugar (conversion from harvested weight cane = 0.1); maize yield relates to in dry weight grain (conversion from harvested weight = 0.875); soybean yield relates to dry weight grain (conversion from harvested weight = 0.9); groundnut yield relates to dry weight grain (conversion from harvested weight in shells = 0.67); banana yield relates to dry weight fruit (conversion from fresh fruit = 0.35); coconut yield relates to dry weight copra (conversion from harvested weight coconut = 0.175); citrus yield relates to dry weight fruit (conversion from harvested weight fruit = 0.15); cassava yield relates to dry weight roots (conversion from harvested weight roots = 0.35); Jatropha yield relates to vegetable oil; miscanthus yield relates to dry weight above ground biomass.

[3] The suitability index SI reflects the spatial suitability make-up of a pixel in accordance with the definition of suitability classes below, namely as: SI = 100*(VS*0.9 + S*0.7 + MS*0.5 + 0.3*mS*0.3 + VmS*0.15)/0.9.

AEZ Suitability Class			Percentage of maximum yield
Prime land	**VS**	Very suitable land	80-100
Good land	**S**	Suitable land	60-80
	MS	Moderately suitable land	40-60
Poor land	**mS**	Marginally suitable land	20-40
	VmS	Very marginally suitable land	5-20
	NS	Not suitable land	<5

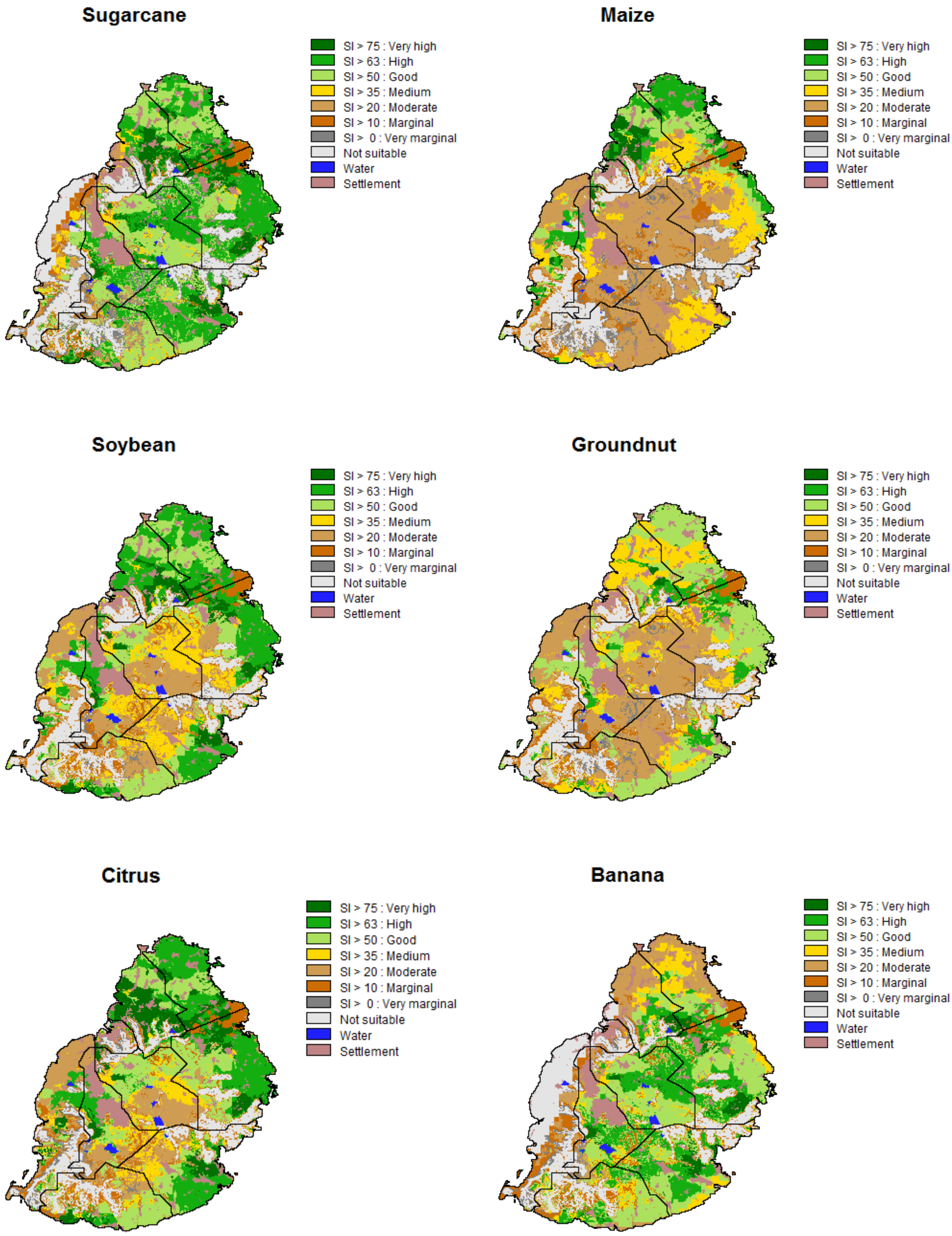

Figure 11a: Rain-fed crop suitability for sugarcane, maize, soybean, groundnut, banana, high inputs, reference climate (1961-90).

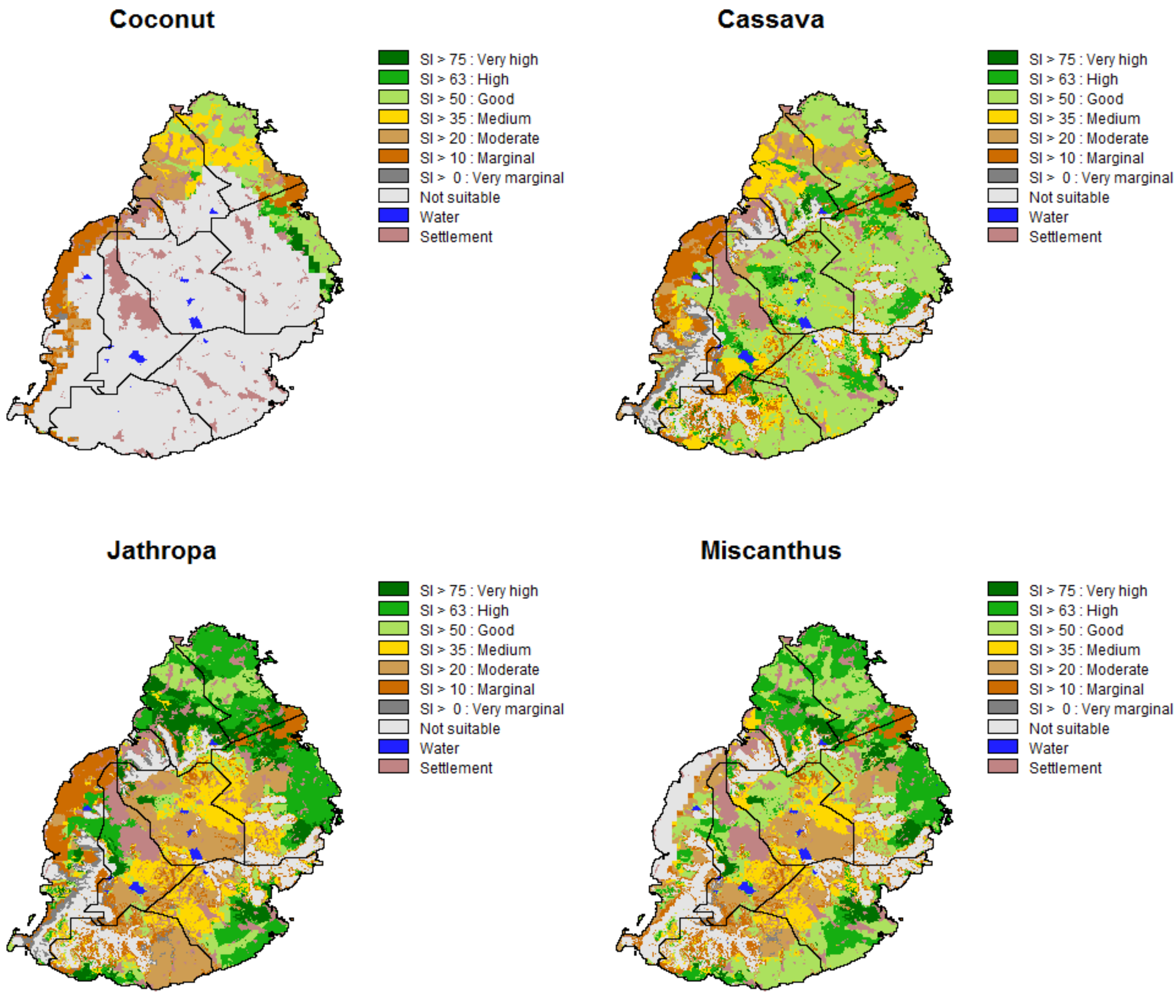

Figure 11b: Rain-fed crop suitability for coconut, citrus, cassava, jatropha and miscanthus, high inputs, reference climate (1961-90).

As shown in Figure 11, prime and good land for rain-fed sugarcane is widely spread over mainly northern, central and eastern parts of the island. Prime and good land for citrus is located as well in northern, and eastern areas, but due to wetness less in the central part of the island. Most good and prime land for maize is found in the northern part, some along the eastern coast and some areas in the west at some distance from the coast line. For cassava, there is only little prime quality land as compared to other crops. Moisture and temperature regime requirements of cassava limit the suitable land occurrence to the northern and north-eastern coastal areas. In addition soil conditions in widespread areas dominated by Vertisols (clayey swell and shrink soils) are, at best, sub-optimal for root crops like cassava, yam and potato.

Sugarcane

The suitability for sugarcane varies substantially across regions, as shown in the sugarcane suitability profiles by district (Figure 12). More than 40% of the territory of Mauritius is not suitable or only marginally suitable for rain-fed sugarcane for reasons of low rainfall, steep slopes or shallow soils. Almost 35% is moderately suitable or suitable (good land) and about 25% is very suitable i.e., prime land for sugarcane (part of this prime sugarcane land is recently being converted to built-up land).

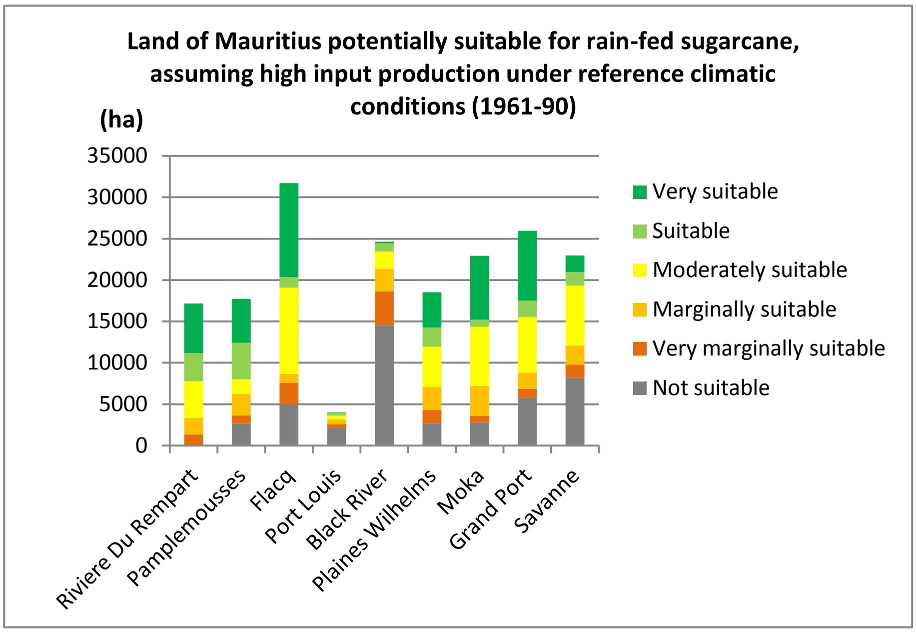

Figure 12: Suitability for the production of rain-fed sugarcane

When considering current rain-fed cultivated land only, the AEZ results show that only a small part of this land is not suitable or only very marginally suitable for rain-fed cultivation of sugarcane (17%). Three quarters of the rain-fed cultivated land is prime or good rain-fed sugarcane land. Figure 13 shows sugarcane suitability profiles of rain-fed cultivated land by district. Most of the prime rain-fed sugarcane land is found in Flacq and Grand Port districts.

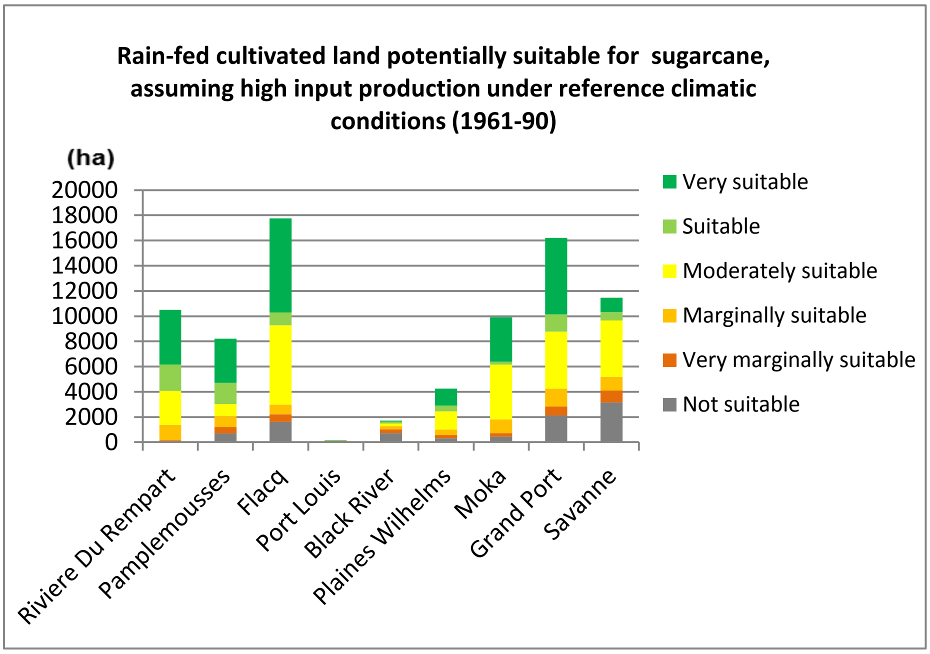

Figure 13: Suitability of rain-fed cultivated land for the production of sugarcane

The *irrigated* cultivated land mainly equipped with overhead irrigation[4], is according to AEZ analysis generally very suitable for sugarcane, i.e., 6,500 ha of the 19,460 ha is prime sugarcane land. Only a

[4] About one third of the sugarcane is grown under supplementary irrigation. The main system used is the central pivot overhead irrigation system. Surface and drip irrigation are minor and mainly used for non-sugarcane cash crops. There is an

small fraction of the irrigated cultivated land was assessed as not suitable or very marginally suitable for sugarcane (about 5%). Figure 14 shows sugarcane suitability profiles of irrigated cultivated land by district. Most of the prime irrigated sugarcane land is found in Pamplemousses district.

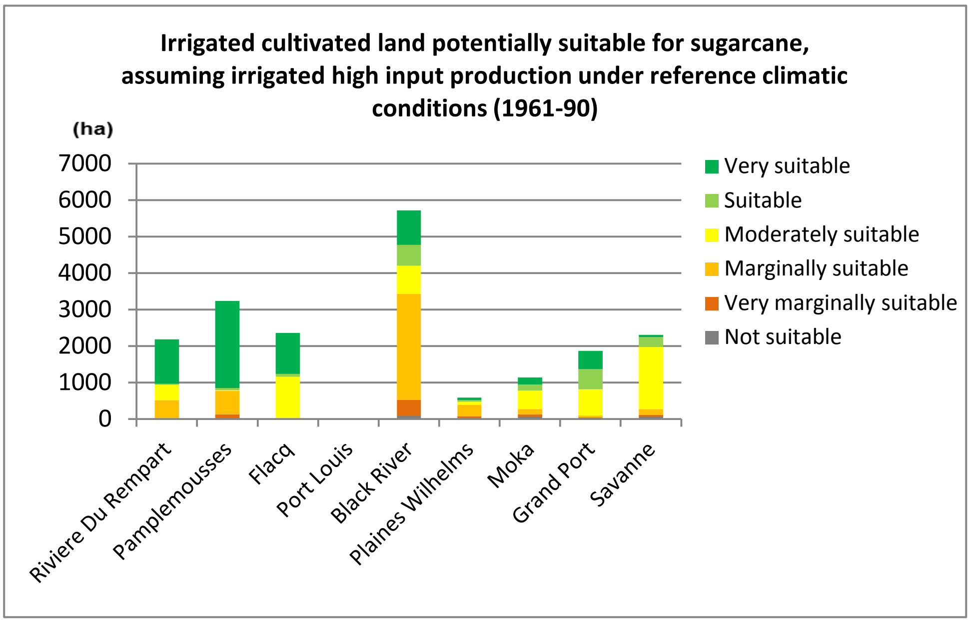

Figure 14: Suitability of irrigated cultivated land for the production of sugarcane

3.2 Actual versus potential yields

Actual achieved yields are compared with potentially attainable yields of current cultivated land. Table 8 presents for six crops/feedstocks actual harvested areas and attained yields; potential suitable areas and attainable yields (under high input and management assumptions), and maximum potential attainable yields of prime locations.

Results show that actually achieved sugar yields are close to the potential as assessed with AEZ, namely 7,700 and 9,538 kg/ha respectively, which suggests an apparent yield gap of only less than 20% in prime and good locations.

For cassava, maize and citrus, the comparison between actually attained yields in tiny harvested areas with average potentially attainable yields of suitable cultivated land areas is without any real meaning. More interesting for these crops is comparison of achieved yields with yields achievable in prime and good land or with maximum potential yields found in Mauritius' cultivated land. Achieved maize yields are 92 % of achievable yields in prime and good locations and 56 % as compared to maximum potential yields. For cassava these ratios are 77% and 47% and for citrus 78% and 55%. Miscanthus and jatropha are currently not grown (no statistics). In particular miscanthus was assessed as having high potentials in Mauritius.

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overall decline of 7 % of irrigated areas since 2007; surface irrigation shows the strongest decline (more than 50%). Irrigated land loss is almost fully to be attributed to urbanization.

Year	Irrigation by types (ha)			
	Overhead	Surface	Drip	Total
2007	17,602	1,618	2,101	21,321
2008	18,264	1,053	2,140	21,457
2009	18,818	875	1,850	21,543
2010	17,023	714	2,110	19,847

Table 8: Yield gaps

Crop/Feedstock	Actual production (2009) Harvested area (ha)	Actual production (2009) Yield* (kg/ha)	Potential production Suitable** area (ha)	Potential production Yield* (kg/ha)	Maximum potential yield (kg/ha)
Sugarcane (sugar)	60,503	7,700	73,710	9,538	13,515
Cassava (root)	27	5,250	75,380	6,787	11,186
Maize (grain)	101	7,000	35,880	7,638	12,403
Miscanthus (agb)	n.a.	n.a.	65,810	21,440	3,2250
Jatropha (veg. oil)	n.a.	n.a.	54,470	2,909	4,074
Citrus (fruit)	132	3,000	69,640	3,841	5,432

* See Footnote 2.

** Total cultivated land assessed is 99,580 ha. The suitable cultivated land area presented here includes prime and good land (VS, S, MS) and varies by crop/feedstock assessed. In the case of sugarcane and maize, rain-fed production potential of rain-fed cultivated land and irrigated production potential from irrigated cultivated land is combined. Potential production of cassava, miscanthus, jatropha and citrus refers to rain-fed production potentials of total cultivated land.

3.3 Climate change impacts on crop suitability and yields

The analysis as carried out for reference climate conditions was also undertaken for three different climate scenarios derived from outputs of three available GCMs for the A2 IPCC scenarios (Nakicenovic et al. 2000; Fischer et al. 2002b). As time horizon the 2050s were chosen. The scenarios are: Hadley CM3/A2/2050s (Hadley Centre, UK Meteorological Office), CSIRO MK2/A2/2050s (Australia's Commonwealth Scientific and Industrial Research Organisation, Australia) and MPI ECHAM4/A2/2050s (Max-Planck-Institute for Meteorology, Germany).

In Table 9 selected results of the analysis for sugarcane, cassava, maize, miscanthus, jatropha and citrus are summarized by district showing the percentage occurrence of prime and good agricultural land[5] for current and future climates, i.e., reference (1961-90) climatic conditions and for the three climate scenarios. AEZ results show that projected climate change affects crop production differently for different crops and differently in different parts of Mauritius. Tables 9 and 10 show that in western districts Black River and Port Louis, which are the driest districts of Mauritius, climate change reduces rain-fed productivity across the board for all crops assessed under all future scenarios tested for 2050. In the northern districts of Mauritius (Riviere Du rampart and Pamplemousses) some long duration crops (sugarcane, cassava) are affected by additional water stress which significantly reduces production.

Table 9: Extents of prime and good agricultural land for rain-fed sugarcane, cassava, maize, miscanthus, jatropha and citrus in total land area

Reference Climate

District	Extent (000ha)	Prime and good agricultural land (%) Sugarcane	Cassava	Maize	Miscanthus	Jatropha	Citrus
Riviere Du Rempart	17.2	81	80	75	82	82	80
Pamplemousses	17.7	65	69	64	70	70	69
Flacq	31.7	73	73	30	60	55	67
Port Louis	4.0	21	24	31	29	30	25
Black River	24.6	13	18	25	18	20	21
Plaines Wilhelms	18.5	62	61	19	53	46	54
Moka	23.0	68	70	4	54	33	56
Grand Port	25.9	66	68	21	57	49	58
Savanne	23.0	47	53	7	43	21	45
Mauritius (total)	185.6	58	60	29	53	45	55

[5] Prime and good agricultural land comprise of VS, S and MS land in the AEZ land suitability classification, see Footnote 3.

Hadley CM3/A2/2050s

District	Extent (000ha)	Prime and good agricultural land (%)					
		Sugarcane	Cassava	Maize	Miscanthus	Jatropha	Citrus
Riviere Du Rempart	17.2	62	80	77	80	82	80
Pamplemousses	17.7	60	67	65	69	70	69
Flacq	31.7	73	73	36	60	57	72
Port Louis	4.0	12	22	31	25	29	25
Black River	24.6	7	16	25	15	20	18
Plaines Wilhelms	18.5	59	64	21	52	47	55
Moka	23.0	68	70	6	59	34	62
Grand Port	25.9	67	68	25	54	50	60
Savanne	23.0	48	53	8	43	21	47
Mauritius (total)	185.6	55	60	31	52	46	57

CSIRO MK2/A2/2050s

District	Extent (000ha)	Prime and good agricultural land (%)					
		Sugarcane	Cassava	Maize	Miscanthus	Jatropha	Citrus
Riviere Du Rempart	17.2	71	80	77	80	82	81
Pamplemousses	17.7	60	67	65	69	70	70
Flacq	31.7	73	73	36	60	57	72
Port Louis	4.0	15	22	31	26	29	25
Black River	24.6	9	17	25	17	19	20
Plaines Wilhelms	18.5	59	64	21	52	47	58
Moka	23.0	68	70	5	56	32	63
Grand Port	25.9	67	68	25	56	50	61
Savanne	23.0	49	54	8	44	20	49
Mauritius (total)	185.6	56	60	31	52	45	58

MPI ECHAM4/A2/2050s

District	Extent (000ha)	Prime and good agricultural land (%)					
		Sugarcane	Cassava	Maize	Miscanthus	Jatropha	Citrus
Riviere Du Rempart	17.2	47	73	81	73	82	81
Pamplemousses	17.7	42	63	68	64	66	69
Flacq	31.7	71	74	48	63	62	74
Port Louis	4.0	2	10	30	15	17	23
Black River	24.6	4	8	19	8	10	15
Plaines Wilhelms	18.5	58	65	29	59	51	65
Moka	23.0	67	70	18	67	51	71
Grand Port	25.9	65	69	35	61	57	68
Savanne	23.0	49	57	20	50	26	54
Mauritius (total)	185.6	50	59	38	54	49	61

However, short duration crops, like maize, benefit from reduced humidity in these districts; it is lowering pest and disease pressures and is resulting in higher production. For all crops assessed, with the exception of sugarcane, in the central and eastern districts (Moka, Plain Wilhems, Grand port and Savanna) climate change generally improves crop production in particular for maize. Sugarcane production, however, turns out the same or slightly lower in these districts.

From the three future climate scenarios used for this assessment the Max-Planck (Echam4/A2/2050s) scenario predicts the strongest climate change signal. In particular rainfall reduces considerable (see section 2.3.1) and therefore forecasts largest production losses.

Figure 15 summarizes for Mauritius the climate change impacts on extents of prime and good agricultural land for rain-fed sugarcane. The total amount of prime and good agricultural land as a whole slightly decreases with climate change for sugarcane, remains about the same as under reference climate for cassava, miscanthus and increases for maize, jatropha and citrus.

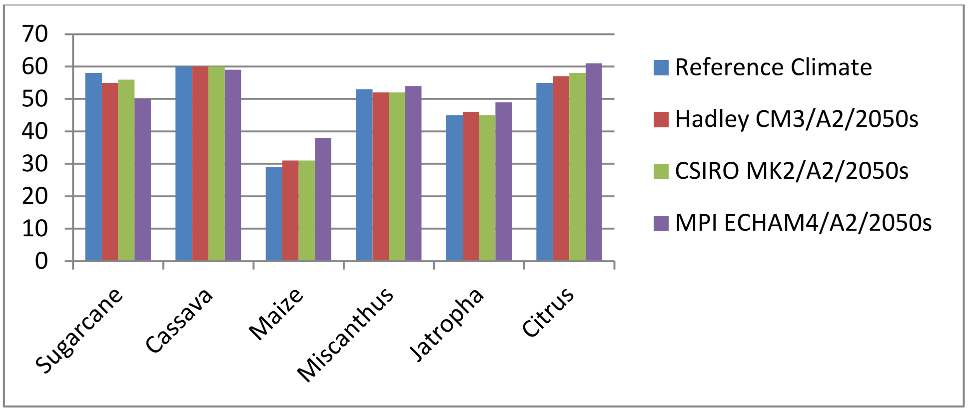

Figure 15: **Percentage occurrence of prime and good agricultural land**

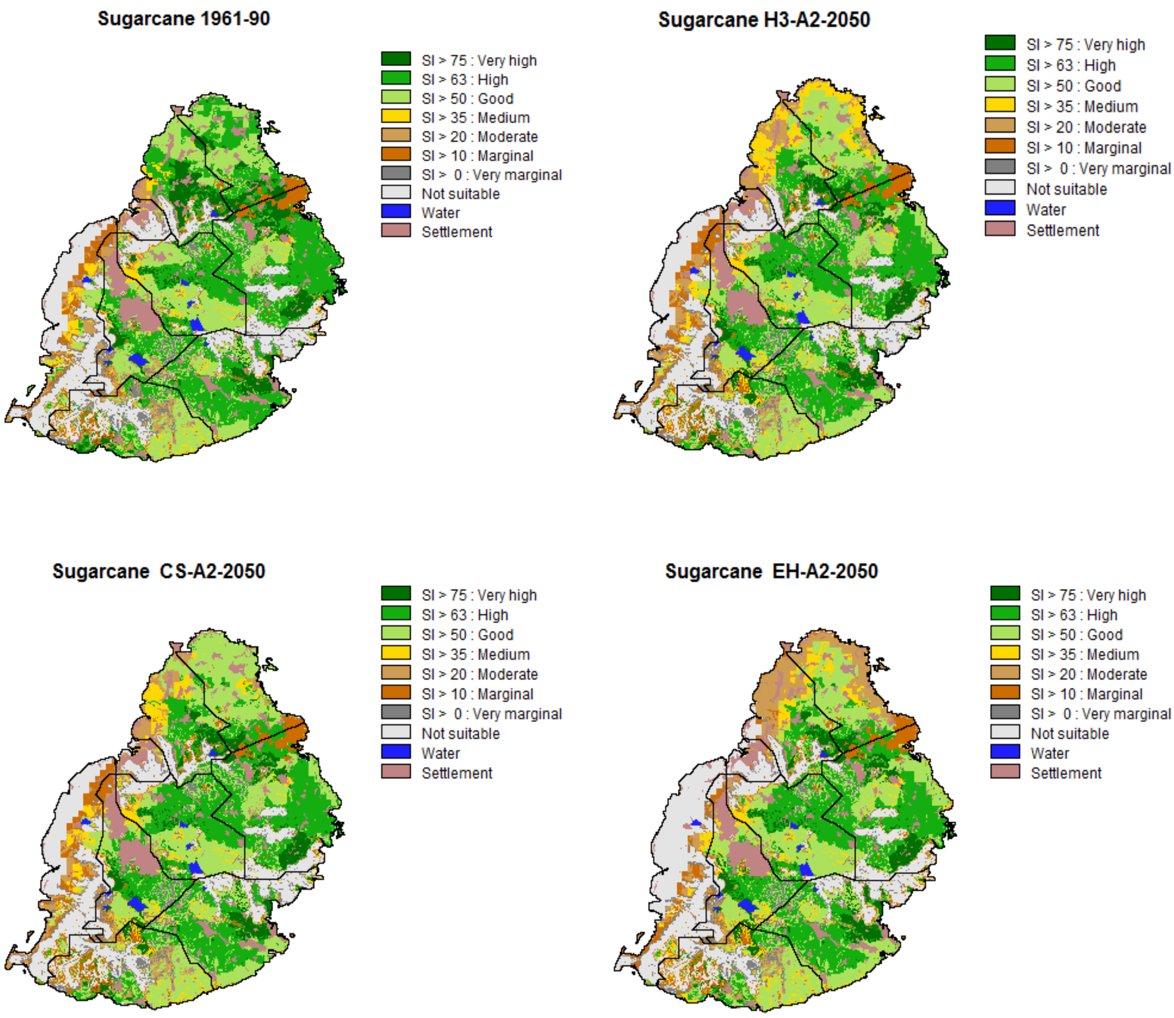

Figure 16: **Land suitability for rain-fed sugarcane at high levels of inputs for reference climate and climate change conditions**.

Figure 16 presents a comparison of suitability for sugarcane under reference climate and changed climate conditions for the 2050s. Figure 17 shows results in terms of attainable rain-fed yields. All three scenarios predict a decrease of rain-fed prime and good land in particular in the northern and dry western parts of the island, although to different degrees across scenarios. The negative impact is foremost caused by less favorable soil moisture conditions.

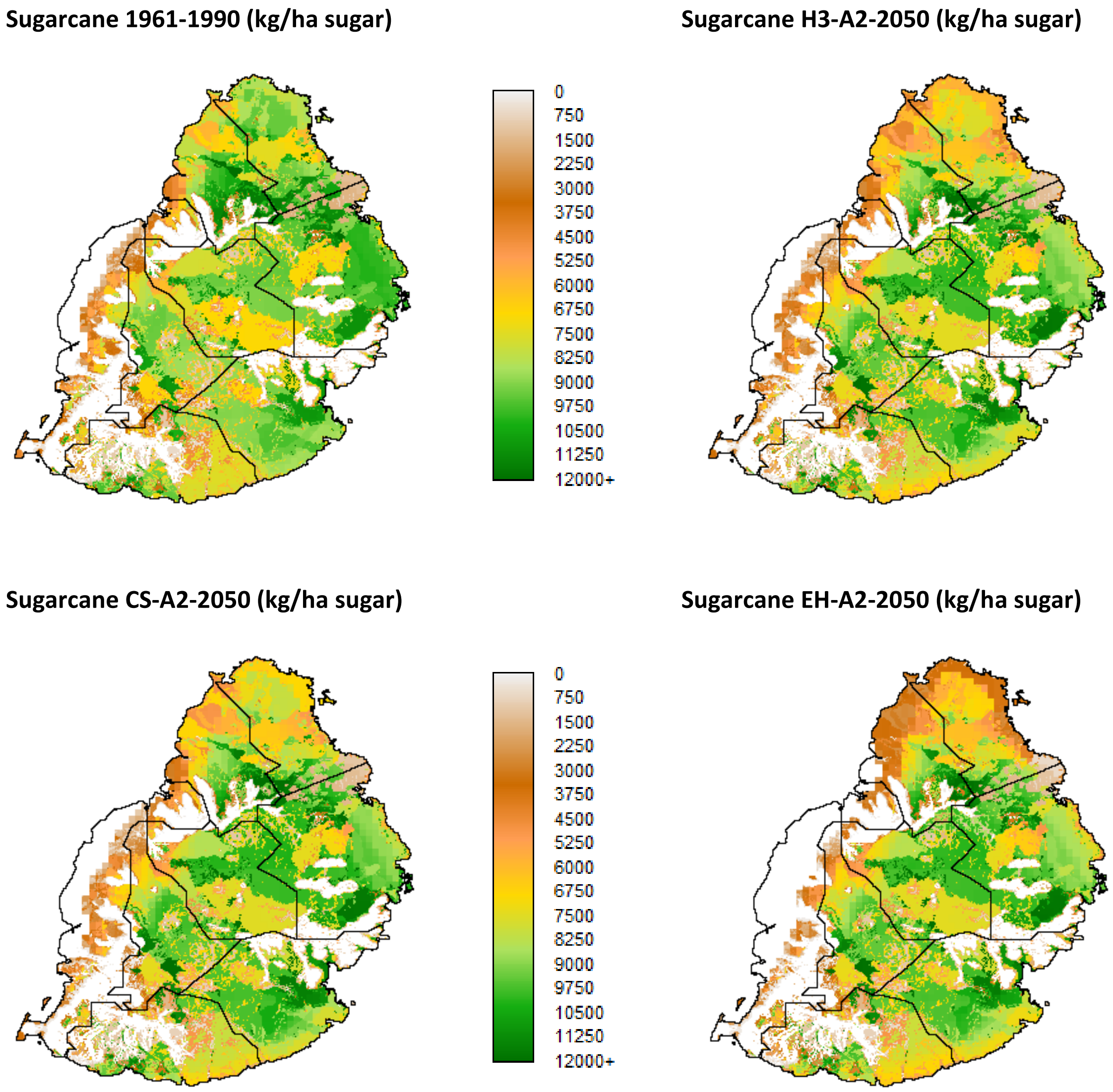

Figure 17: **Attainable yields of rain-fed sugarcane at high levels of inputs for reference climate and climate change conditions**

Looking at current cultivated land only, Table 10 presents rain-fed suitability results under reference climate and under climate change conditions for the 2050s.

Table 10: **Extents of prime and good agricultural land for rain-fed sugarcane, cassava, maize, miscanthus, jatropha and citrus in current cultivated land**

Reference Climate

District	Extent (000ha)	Prime and good cultivated land * (%)					
		Sugarcane	Cassava	Maize	Miscanthus	Jatropha	Citrus
Riviere Du Rempart	12.7	85	86	77	86	86	86
Pamplemousses	11.5	74	78	72	78	78	79
Flacq	20.1	85	86	34	69	63	79
Port Louis	0.1	14	14	14	14	14	14
Black River	7.4	22	29	39	30	30	36
Plaines Wilhelms	4.8	71	74	33	69	54	70
Moka	11.1	81	83	6	64	35	68
Grand Port	18.1	76	78	25	66	56	67
Savanne	13.8	60	67	10	55	22	58
Mauritius (total)	99.6	73	76	36	66	55	70

Hadley CM3/A2/2050s

District	Extent (ha)	Prime and good cultivated land (%) Sugarcane	Cassava	Maize	Miscanthus	Jatropha	Citrus
Riviere Du Rempart	12.7	70	86	80	86	86	86
Pamplemousses	11.5	69	77	73	78	78	79
Flacq	20.1	85	86	41	68	66	85
Port Louis	0.1	14	14	14	14	14	14
Black River	7.4	11	26	38	26	31	30
Plaines Wilhelms	4.8	69	75	37	68	59	71
Moka	11.1	81	83	8	71	43	76
Grand Port	18.1	76	78	30	63	59	70
Savanne	13.8	60	66	10	56	22	62
Mauritius (total)	99.6	69	75	39	66	57	73

CSIRO MK2/A2/2050s

District	Extent (ha)	Prime and good cultivated land (%) Sugarcane	Cassava	Maize	Miscanthus	Jatropha	Citrus
Riviere Du Rempart	12.7	79	86	80	86	86	87
Pamplemousses	11.5	70	77	72	78	78	79
Flacq	20.1	85	86	41	68	65	85
Port Louis	0.1	14	14	14	14	14	14
Black River	7.4	14	28	37	28	29	34
Plaines Wilhelms	4.8	69	75	37	69	61	73
Moka	11.1	81	83	7	67	44	76
Grand Port	18.1	76	78	29	65	59	71
Savanne	13.8	60	67	11	57	22	63
Mauritius (total)	99.6	71	75	39	66	57	74

MPI ECHAM4/A2/2050s

District	Extent (ha)	Prime and good cultivated land (%) Sugarcane	Cassava	Maize	Miscanthus	Jatropha	Citrus
Riviere Du Rempart	12.7	58	82	85	82	87	87
Pamplemousses	11.5	51	73	77	73	75	79
Flacq	20.1	85	88	55	74	70	88
Port Louis	0.1	14	14	14	14	14	14
Black River	7.4	7	15	30	15	16	24
Plaines Wilhelms	4.8	67	76	53	71	61	76
Moka	11.1	80	83	26	82	58	84
Grand Port	18.1	74	79	41	70	65	78
Savanne	13.8	61	71	28	65	26	70
Mauritius (total)	99.6	65	75	50	69	60	77

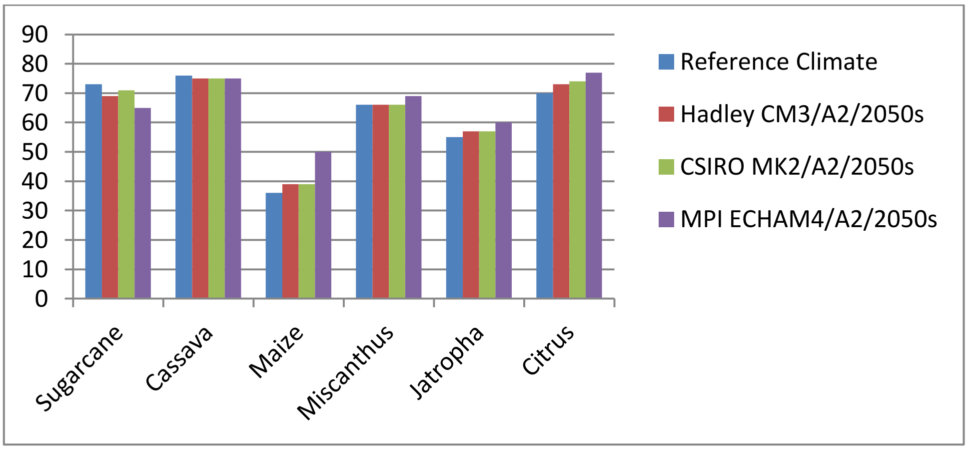

Figure 18: Percentage occurrence of prime and good agricultural land within current cultivated land

With climate change the rain-fed growing period conditions within the current cultivated land become more favorable for maize, jatropha and citrus. For sugarcane climatic conditions are getting less favorable in all three climate change projections considered (See Figure 18).

For crops with more specific temperature narrow and moisture requirements impacts can vary substantially. For instance, for coconut and oil palm, climatic conditions are currently for most part of the island unfavorable. With climate change some crucial climatic thresholds are surpassed, resulting in increases of suitable land and attainable yields. In contrast to the climate change impacts on coconut and oil palm, white potato, not tolerant to high temperatures, loses suitable areas and average yields decrease.

Figure 19 presents comparisons between suitability for coconut, oil palm and white potato under reference climate and changed climate conditions for the 2050s.

The analysis shows substantial increases of suitable areas and yields for coconut and, and less pronounced, for oil palm due to mainly warmer conditions with climate change. With climate change both crops emerge very strongly in the wetter eastern coastal areas. Suitable area and yield for white potato, for most part only moderately suitable under reference climate conditions, decreases due to low tolerance of high temperatures during its growing season. The analysis shows that the suitable area for white potato decreases and contracts to the higher center parts of Mauritius.

3.4 Climate change impact on irrigation water requirements

In total Mauritius has currently close to 20,000 ha irrigated land. In the following we look at (i) the quality of this irrigated land vis-à-vis sugar cane production (ii) the total water requirements and net irrigation requirements[6] assuming all irrigated land were under sugarcane (In fact almost all irrigated land is used for sugarcane, i.e., 95%), and (iii) climate change impacts on water requirements and attainable yields.

More than one-fifth of the cultivated land in Mauritius is equipped for irrigation, foremost overhead irrigation systems, to supplement soil moisture during the dry season. By comparing total net water requirements of sugarcane with soil moisture available from rainfall, the net amount of irrigation water needed to avoid water stress is calculated. Table 11 provides for current cultivated land equipped with irrigation the total crop water requirements and shows calculated net irrigation water requirements. Values refer to reference climatic conditions (1961-90). Due to large spatial variations of rainfall across the island, the relative amount of net irrigation water to be supplied varies by location between about 10 and 40 % of total water requirements.

With climate change total water requirements increase due to higher evaporative demand caused mainly by higher temperatures. The irrigated sugar production increase for the different scenarios is in the order of 5%. Simulated net irrigation water requirements (the difference between total crop water requirement and soil moisture availability from rainfall) increases are much higher. This is explained by changes in rainfall regime, partly due to decrease of total rainfall but also due to more concentrated distribution of rainfall with as consequence increased irrigation requirements to avoid elongated periods with water stress.

[6] Net irrigation requirement refer to crop water requirements only. Extra water will be needed to cope with losses in irrigation infrastructure and efficiency of application.

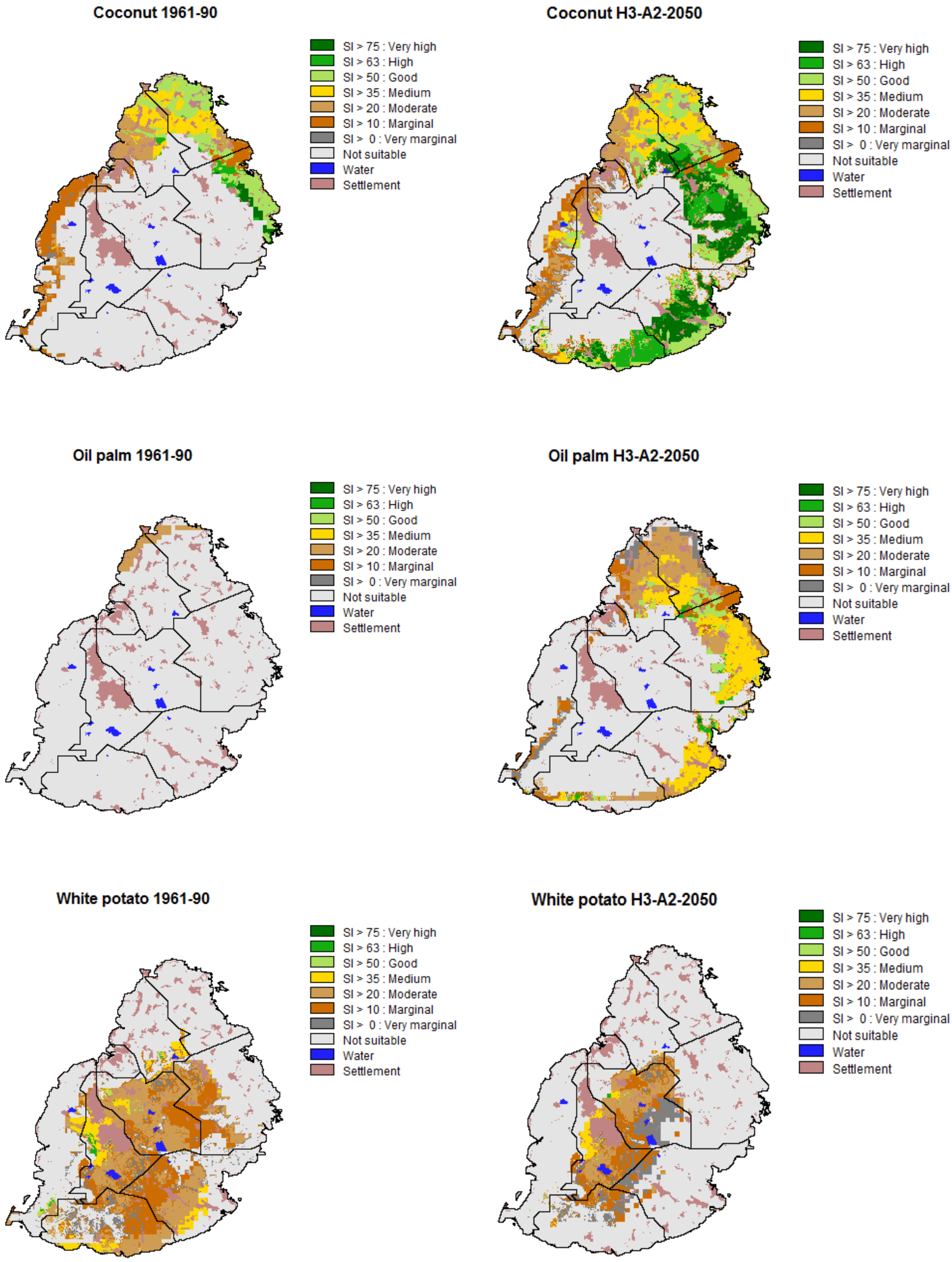

Figure 19: Land suitability for rain-fed coconut oil palm and white potato at high levels of inputs for reference and future climate conditions

Table 11: Water requirements of sugarcane and potential sugar production in current irrigated areas by district for reference climatic conditions (1961-90)

	Irrigated land (000ha)	Total water requirements (mm)	Net Irrigation water requirements (mm)	Share irrigated in total water requirements (%)	Net Irrigation water requirements ($10^6 m^3$)	Potential Sugar Production (000t)
Riviere Du Rempart	2.2	1,268	250	20	5.5	18.0
Pamplemousses	3.3	1,307	342	26	11.3	28.3
Flacq	2.4	1,177	136	12	3.3	21.2
Port Louis						0.0
Black River	5.7	1,220	562	46	32.0	34.1
Plaines Wilhelms	0.6	1,229	375	31	2.3	3.3
Moka	1.2	1,038	124	12	1.5	7.9
Grand Port	1.9	963	85	9	1.6	15.6
Savanne	2.3	1,003	77	8	1.8	15.5
Mauritius	19.5	1,174	302	26	59.3	143.7

Tables 12 to 14 provide for current cultivated land equipped with irrigation the total water requirements and shows calculated net irrigation requirements under climate change predicted for the 2050s. Values in Tables 12 to 14 refer to IPCC SRES A2 emission scenario for respectively the Headley Centre, UK Meteorological Office coupled climate model 3 (H3-A2-2050); the CSIRO: Australian Commonwealth Scientific and Research Organization Mark 2 Model (CS-A2-2050), and Max-Planck-Institute for Meteorology GCM model (EH-A2-2050**).**

Table 12: Water requirements of sugarcane and potential sugar production in current irrigated areas by district for future climatic conditions (H3-A2-2050)

	Irrigated land (000ha)	Total water requirements (mm)	Net Irrigation water requirements (mm)	Share irrigated in total water requirements (%)	Net Irrigation water requirements ($10^6 m^3$)	Potential Sugar Production (000t)
Riviere Du Rempart	2.2	1,289	376	29	8.3	18.3
Pamplemousses	3.3	1,328	461	35	15.2	28.8
Flacq	2.4	1,196	256	21	6.1	22.0
Port Louis	n.a.	n.a.	n.a.	n.a.	n.a.	0.0
Black River	5.7	1,241	645	52	36.8	35.2
Plaines Wilhelms	0.6	1,249	485	39	2.9	3.5
Moka	1.2	1,055	224	21	2.7	8.5
Grand Port	1.9	979	187	19	3.6	16.4
Savanne	2.3	1,020	178	17	4.1	16.4
Mauritius	19.5	1,193	406	34	79.7	149.1

Climate change brings some small improvement to irrigated sugarcane production in the order of 5% only, while net irrigation water requirements increase substantially, depending on climate scenario by 32% to 67%. Table 15 summarizes by climate scenario, for all irrigated areas in Mauritius the total net amount of irrigation water required to avoid water stress and the respective changes in potential irrigated sugar production.

For comparison to irrigated sugarcane production potentials under climate change, its changes in net irrigation requirements and production have been set against hypothetical double cropping of maize in the same irrigated area. In this analysis rain-fed production for maize was assumed during the rainy season (no irrigation) and irrigated production during the dry season. The results are shown in Table 16 below.

Table 13: Water requirements of sugarcane and potential sugar production in current irrigated areas by district for future climatic conditions (CS-A2-2050)

	Irrigated land (000ha)	Total water requirements (mm)	Net Irrigation water requirements (mm)	Share irrigated in total water requirements (%)	Net Irrigation water requirements ($10^6 m^3$)	Potential Sugar Production (000t)
Riviere Du Rempart	2.2	1,328	362	27	8.0	18.3
Pamplemousses	3.3	1,368	453	33	14.9	28.7
Flacq	2.4	1,233	237	19	5.7	22.0
Port Louis	n.a.	n.a.	n.a.	n.a.	n.a.	0.0
Black River	5.7	1,280	654	51	37.3	35.1
Plaines Wilhelms	0.6	1,287	475	37	2.9	3.5
Moka	1.2	1,088	210	19	2.5	8.6
Grand Port	1.9	1,009	167	17	3.2	16.3
Savanne	2.3	1,052	156	15	3.6	16.5
Mauritius	19.5	1,230	398	32	78.1	148.8

Table 14: Water requirements of sugarcane and potential sugar production in current irrigated areas by district for future climatic conditions (EH-A2-2050)

	Irrigated land (000ha)	Total water requirements (mm)	Net Irrigation water requirements (mm)	Share irrigated in total water requirements (%)	Net Irrigation water requirements ($10^6 m^3$)	Potential Sugar Production (000t)
Riviere Du Rempart	2.2	1,284	481	37	10.6	18.5
Pamplemousses	3.3	1,323	591	45	19.5	29.1
Flacq	2.4	1,191	326	27	7.8	22.2
Port Louis	n.a.	n.a.	n.a.	n.a.	n.a.	0.0
Black River	5.7	1,235	777	63	44.3	35.5
Plaines Wilhelms	0.6	1,243	622	50	3.7	3.5
Moka	1.2	1,050	292	28	3.5	8.6
Grand Port	1.9	974	232	24	4.4	16.6
Savanne	2.3	1,014	220	22	5.1	16.6
Mauritius	19.5	1,188	505	43	98.9	150.6

Table 15: Impacts of climate change on net irrigation water requirements and production potential of sugarcane in current irrigated areas

	Net irrigation water requirements			**Production potential**	
	Current irrigated area (mm)	**Current irrigated area ($10^6 m^3$)**	**Difference with reference climate conditions (%)**	**Current irrigated area (000t)**	**Difference with reference climate conditions (%)**
Reference (1961-90)	302	59.3	-	143.7	-
H3-A2-2050	406	79.7	34	149.1	4
CS-A2-2050	398	78.1	32	148.8	5
EH-A2-2050	505	98.9	67	150.6	4

From results presented in Table 15 and Table 16, it can be seen, depending on climate change scenario, that potential irrigated sugar cane production would increase 4 to 5% and double cropping with one rain-fed and one irrigated maize crop would increase between 9% and 18%. Another finding is that irrigated sugarcane is much more irrigation water demanding than irrigated maize. For reference climatic conditions, average net irrigation water requirements of sugarcane were estimated to be 303 mm. For maize the requirements would be 159 mm. Hence, sugarcane requires almost twice as much irrigation water compared to maize. With climate change and depending on climate scenario, water requirements for sugarcane increase with 32 to 67 %; for the irrigated maize crop from 10% to 50 %.

Table 16: Total crop water requirements and net irrigation water requirements for sugarcane and maize in current irrigated cultivated land.

Crop	Climate	Total crop water requirements (mm)	Net irrigation water requirements (mm)	Potential Production (000t)	Potential Biofuel Production* (TJ)
Sugarcane (sugar)	Reference climate	**1,175**	**303**	**143,7**	**2,143**
	Hadley CM3/A2/2050s	**1,194**	**408**	**149.1**	**2,223**
	CSIRO MK2/A2/2050s	**1,230**	**399**	**148.8**	**2,219**
	MPI ECHAM4/A2/2050s	**1,189**	**506**	**150.6**	**2,245**
Maize (total) (grain)	Reference climate	**493**	**159**	**211.4**	**2,072**
	Hadley CM3/A2/2050s	**501**	**183**	**231.6**	**2,270**
	CSIRO MK2/A2/2050s	**514**	**176**	**230.8**	**2,262**
	MPI ECHAM4/A2/2050s	**503**	**239**	**250.3**	**2,453**

* for conversion factors see Table 17; in the case of sugarcane the energy content of bagasse is not considered in this case

3.5 Bio-energy feedstock potentials

The analysis has been carried out as follows (see box):

- Sugarcane potentials have been calculated separately for the rain-fed and irrigated part of the cultivated land. Energy conversions for sugarcane are based on sugar and bagasse production estimates.
- Cassava potentials have been calculated for rain-fed production only. The assessment comprises both rain-fed and irrigated cultivated land. Energy conversion for cassava is based on dry weight root production estimates.
- Maize potentials have been calculated for rain-fed production and irrigated production. It was assumed that one rain-fed maize crop would be grown during the rainy season in both rain-fed and irrigated cultivated land and that in addition in the “off season” one irrigated crop of maize would be grown in the irrigated cultivated land. Energy conversion for maize is based on dry weight grain production estimates.
- Miscanthus potentials have been calculated for rain-fed production only. The assessment comprises both, rain-fed and irrigated cultivated land. Energy conversion for miscanthus is based on dry weight above ground biomass production estimates under the assumptions of a “futuristic” second generation ethanol production pathway.
- Jatropha potentials have been calculated for rain-fed production only[7]. The assessment comprises both, rain-fed and irrigated cultivated land. Energy conversion for jatropha is based on oil production estimates.

Production potentials for alternative main bio-energy feedstocks were compared with biofuel potentials that can be achieved with sugarcane. Potential energy production of sugarcane, cassava, maize, miscanthus and jatropha have been calculated and compared for reference climate conditions as well as for the three climate scenarios for the 2050s.

Efficiencies of conversion from harvested produce to energy equivalent of the respective liquid fuel vary considerably. Table 17 provides an overview of conversions used in the analysis.

[7] So far none of the jatropha species have been properly domesticated and as a result its productivity is highly variable. The yield performance of Jatropha is largely uncertain when transferred to different ecological circumstances and management.

Table 17: Energy conversion coefficients for sugar and bagasse from sugarcane, cassava root, maize grain, miscanthus biomass and jatropha oil production

Feedstock	Produce	Energy equivalents per ton of harvested produce (DW)		
		Fuel (l)*	Energy (GJ)	Oil equivalent (toe)
Sugarcane	sugar	700	14.91	0.357
Sugarcane	bagasse	n.a.	19.2	0.46
Cassava	root	510	10.9	0.26
Maize	grain	460	9.8	0.23
Miscanthus	AGB	300	6.4	0.15
Jatropha	veg. oil	1087	36.8	0.88

* Equivalent liter ethanol (all except jatropha) or vegetable oil (jatropha)

Sugarcane: 70 liter ethanol /ton sugarcane [FAO, 2008] / 0.1 ton sugar/ton sugarcane [GAEZ] -->700 liter ethanol /ton sugar × 21.3 MJ/liter ethanol [EU, 2003] = 14.9 GJ/ton ; bagasse: approximately 0.1 ton dry bagasse/ton sugarcane × 19.2 MJ/kg [da Rosa, 2005]

Cassava: 180 liter ethanol/ fresh ton cassava [FAO, 2008] = 180 × 1/0.35 (65% moisture content) [GAEZ] = 510 liter ethanol/dry ton cassava × 21.3 MJ/liter ethanol [EU, 2003] =10.9 GJ/dry ton cassava

Miscanthus: Hydrolysis ethanol 300 litres ethanol/dry ton [Carriquiry et al, 2010] × 21.3 MJ/liter ethanol [EU, 2003] =6.4 GJ/dry ton miscanthus

Maize: 400 liter ethanol/ fresh ton maize [FAO, 2008] = 400× 1/0.87 (13% moisture content) [GAEZ] = 460 liter ethanol/dry ton maize × 21.3 MJ/liter ethanol [EU, 2003] =9.8 GJ/dry ton maize

Jatropha: density jatropha oil 0.92 kg/ liter [FNR, 2012] --> GAEZ product Oil -> 1 ton = 1086.95 liter; heating value 33.9 MJ/liter or 36.8 MJ/kg [FNR, 2012] = 36.8 GJ/ton jatropha oil.

Tables 18 summarizes by feedstock, reference climate and each climate scenario the production estimates and respective conversions to biofuel (m^3) (where applicable), oil equivalents (ktoe) and energy (TJ).

Results of the AEZ analysis of currently cultivated land for reference climate (Table 18) shows that from the five selected feedstocks sugarcane is out-performing the other feedstocks in terms of energy equivalents (549 ktoe). Here is has been assumed that the sugar is converted to ethanol (245 ktoe) and the bagasse is used for co-firing for the production of electricity (304 ktoe), which more than doubles the energy obtained from sugarcane.

Another promising feedstock is miscanthus, for which however 2nd generation conversion from lignocellulose to ethanol was assumed. In terms of energy equivalents, the conversion of miscanthus to ethanol (254 ktoe) would be slightly superior to the sugar to ethanol conversion of sugarcane. Maize and cassava were estimated to perform substantially lower in energy equivalents namely respectively about 116 and 129 ktoe. Jatropha takes a middle position (175 ktoe); it has the advantage of a well-established, relative simple, low cost conversion technology from vegetable oil to bio-diesel.

Table 18 also shows that the potential production of the different bio-energy feedstocks and associated bio-energy are differently affected by climate change. The potential production of rain-fed and irrigated sugarcane is, depending on climate change scenario, estimated to decrease slightly (<3%) or to remain unchanged. Cassava is estimated to gain with climate change between 6% and 9 %. Maize is estimated to benefit significantly from climate change namely between 9% and more than 20%. Miscanthus potential production is insignificantly affected by climate change; the above ground biomass production varies between -1% and +2%. Jatropha gains with climate change, namely between almost 7% and 14%.

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Table 18: Energy production potential from selected feedstocks in current cultivated land

Reference climatic conditions (1961-90)

Feedstock	Potential production rain-fed land				Potential production irrigated land				Rain-fed and irrigated land
	Produce (000t)	Biofuel (000m^3)	Energy (TJ)	Oil equiv. (ktoe)	Produce (000t)	Biofuel (000m^3)	Energy (TJ)	Oil equiv. (ktoe)	Oil equiv. (ktoe)
Sugarcane (sugar)	538.3	376.8	8026.5	192.2	147.7	103.4	2201.8	52.7	244.9
Sugarcane (bagasse)	518.4	n.a.	9953.1	238.5	142.2	n.a.	2730.3	65.4	303.9
Cassava (root)	403.6	205.8	4399.2	104.9	93.6	47.7	1020.3	24.3	129.2
Maize (grain)	292.4	134.5	2865.4	67.2	211.4	97.2	2071.3	48.6	115.8
Miscanthus (abg)	1306.6	392.0	8362.2	196.0	389.3	116.8	2491.5	58.4	254.4
Jatropha (oil)	152.9	166.2	5626.7	134.6	46.2	50.2	1700.9	40.7	175.3

Hadley CM3/A2/2050s

Feedstock	Potential production rain-fed land				Potential production irrigated land				Rain-fed and irrigated land
	Produce (000t)	Biofuel (000m^3)	Energy (TJ)	Oil equiv. (ktoe)	Produce (000t)	Biofuel (000m^3)	Energy (TJ)	Oil equiv. (ktoe)	Oil equiv. (ktoe)
Sugarcane (sugar)	528.4	369.9	7877.8	188.6	149.1	104.4	2223.4	53.2	241.8
Sugarcane (bagasse)	508.8	n.a.	9768.8	234.0	143.6	n.a.	2757.1	66.1	300.1
Cassava (root)	434.4	221.5	4734.4	112.9	93.8	47.8	1022.1	24.4	137.3
Maize (grain)	318.4	146.5	3120.3	73.2	231.6	106.5	2269.7	53.3	126.5
Miscanthus (abg)	1290.6	387.2	8259.8	193.6	390.4	117.1	2498.6	58.6	252.2
Jatropha (oil)	166.8	181.3	6136.4	146.7	46.4	50.4	1706.8	40.8	187.5

CSIRO MK2/A2/2050s

Feedstock	Potential production rain-fed land				Potential production irrigated land				Rain-fed and irrigated land
	Produce (000t)	Biofuel (000m^3)	Energy (TJ)	Oil equiv. (ktoe)	Produce (000t)	Biofuel (000m^3)	Energy (TJ)	Oil equiv. (ktoe)	Oil equiv. (ktoe)
Sugarcane (sugar)	538.2	376.7	8024.3	192.1	148.8	104.2	2219.1	53.1	245.2
Sugarcane (bagasse)	518.2	n.a.	9950.4	238.4	143.3	n.a.	2751.7	65.9	304.3
Cassava (root)	434.5	221.6	4736.1	113.0	93.6	47.7	1020.3	24.3	137.3
Maize (grain)	320.2	147.3	3137.9	73.6	230.8	106.2	2261.8	53.1	126.7
Miscanthus (abg)	1297.3	389.2	8302.7	194.6	388.9	116.7	2488.7	58.3	252.9
Jatropha (oil)	166.1	180.5	6110.6	146.1	46.2	50.2	1700.9	40.7	186.8

MPI ECHAM4/A2/2050s

Feedstock	Potential production rain-fed land				Potential production irrigated land				Rain-fed and irrigated land
	Produce (000t)	Biofuel (000m^3)	Energy (TJ)	Oil equiv. (ktoe)	Produce (000t)	Biofuel (000m^3)	Energy (TJ)	Oil equiv. (ktoe)	Oil equiv. (ktoe)
Sugarcane (sugar)	514.2	359.9	7666.6	183.6	150.6	105.4	2244.7	53.7	237.3
Sugarcane (bagasse)	495.1	n.a.	9506.8	227.8	145.0	n.a.	2783.5	66.7	294.5
Cassava (root)	447.3	228.1	4875.8	116.3	94.5	48.2	1030.2	24.6	140.9
Maize (grain)*	362.2	166.6	3549.4	83.3	250.5	115.2	2455.1	57.6	140.9
Miscanthus (abg)	1337.6	401.3	8560.6	200.6	393.6	118.1	2519.0	59.0	259.6
Jatropha (oil)	180.2	195.8	6629.5	158.5	46.7	50.8	1719.7	41.1	199.6

* In irrigated cultivated land maize is assumed to be grown twice a year; i.e., during dry season irrigated and during rainy season as rain-fed crop. Also cassava, miscanthus and jathropha are grown without irrigation

Irrigated feedstock production of bio-energy feedstocks benefits more from climate change than rain-fed production (Table 18). Rain-fed sugarcane produces lower with all three climate change scenarios and the potential production of rain-fed miscanthus hardly changes. However rain-fed jatropha, cassava and maize do substantially better with climate change.

Irrigated sugarcane produces, depending on future climatic conditions, between 3 and 5% better than at baseline climate conditions, however, irrigation water requirements of sugarcane increases substantially, namely between 32 and 67% in comparison with baseline climate.

4 Conclusions

Mauritius has rich agricultural resources

Over 80% of Mauritius has suitable soil and terrain conditions for agricultural production.

Sugarcane is well adapted to environmental conditions and is clearly the best yield and production performer among the crops assessed. About 25% of the main island comprises prime conditions for sugarcane growing. Among the other crops that were assessed citrus performs best in terms of extents of prime land (about 20%), soybean about 13%, banana 10%, maize < 8%, and cassava about 5%.

Climate change affects the water balance and suitability of different crops in different ways

The analyses shows that towards the 2050's agro-climatic conditions for rain-fed agricultural production are deteriorating overall, but specially in the relative dry western and northern districts. In particular, future climate conditions as projected with Max-Planck-Institute for Meteorology GCM model (EHA22050) shows strong decreases in rainfall, length of growing period and, as a consequence, in net primary production and implicitly predicts for the 2050s substantial lower overall rain-fed production capacities of land in Mauritius.

With climate change the suitable area of rain-fed sugarcane shrinks slightly. For other crops such as maize, jatropha and citrus extents of prime and good land increases; for cassava soil conditions are the main limiting factor and extents of prime and good land remain stable under climate change. The AEZ analysis shows that for coconut and oil palm, two crops which are currently unimportant in Mauritius, suitable areas and yields are increasing with climate change, while the suitable areas and yield of white potato would considerably decrease by 2050.

Climate change will cause significant increases of irrigation water requirements for sugarcane

Depending on climate change scenario, assessments show that irrigation water requirements of sugarcane in areas currently equipped with irrigation facilities increase between 32 and 67% while sugarcane production in the same area increases by only up to 5%.

The total amount of additional net irrigation water requirements is in the order of 20-40 million m^3. When assuming an irrigation efficiency of 50%, this would mean that per year 40- 80 million m^3 extra water (gross irrigation water requirement) would be required under climate change. This compares with simulated total net and gross irrigation water requirements for current climate of 58 and 116 million $m^{3.}$ These substantial amounts of additional irrigation water requirements also exacerbated by increasing water demands for industrial and domestic use, will need planning for additional water storage systems and may require upgrading of current water supply infrastructure, but also and foremost will call for more efficient use of water resources, in particular for irrigation.

Mauritius has substantial bio energy potentials relative to demand

AEZ assessments show that total energy that can be produced by sugarcane from both sugar (ethanol) and bagasse (electric power) would be highest among all crop base options. For reference climatic conditions, when all cultivated land were to be utilized for sugarcane production, 549 ktoe oil equivalent could be produced and depending on climate scenario, between 532-550 ktoe per year. Except for miscanthus, which could produce for current climate 254 ktoe and under climate change 252-260 ktoe per year, all other feedstocks (assessed for the same cultivated land) would produce substantially less, namely: cassava respectively 129 and 137-141 ktoe; maize respectively 116 and 127-141 ktoe, and jatropha respectively 175 and 187-200 ktoe.

This compares with total imported fossil energy in Mauritius of 1,189 ktoe in 2010 (705 ktoe oil, 70 ktoe LPG and 414 ktoe coal) and 1,195 ktoe in 2011 (727 ktoe oil, 71 ktoe LPG and 398 ktoe coal).

In conclusion, sugarcane could be an effective feedstock for the production of bio-energy, and if channeled to the energy sector, could substitute for a large fraction of current fossil oil imports. Potentially sugarcane derived energy, through co-firing bagasse and producing ethanol from sugar, is equivalent to some 45% of fossil oil imports in 2011. (CSO, 2011)

While the use of bio-energy appears to be an attractive and sound option to increase energy security in Mauritius, the AEZ analysis shows that due to climate change more water will be required in current irrigated areas and that expansion of irrigated areas will be necessary to sustain high sugarcane yields in Mauritius under climate change. This would put an extra burden on the water sector in Mauritius and would certainly intensify competition for water with other sectors.

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