RESEARCH HIGHLIGHTS

CLIMATE CHANGE AND FUTURE CROP SUITABILITY IN RWANDA

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Research Highlights – Climate Change and Future Crop Suitability in Rwanda

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BACKGROUND AND CONTEXT

The Adaptation for Smallholder Agriculture Programme (ASAP) is a flagship programme within the International Fund for Agricultural Development's (IFAD's) portfolio of activities aimed at channelling climate and environmental finance to smallholder farmers, and which allows IFAD country programmes to design projects which integrate considerations of the impacts of climate change on smallholder farmers. To support the integration of climate information and improved knowledge of climate related risks to the smallholder agriculture sector, IFAD commissioned a Climate Risk Analysis to assess the potential impacts of climate change on several crops and commodities in Rwanda.

The full Climate Risk Analysis report (accessible via the IFAD Country page [1]) provides an analysis of *inter alia* i) the current and future climate characteristics of Rwanda; ii) the potential change in the suitability of various crops under projected climate changes; and iii) potential risks and economic impacts related to climate change, as well as potential adaptation options and opportunities to increase climate resilience. The following report provides a brief summary of highlighted results for Rwanda, including: i) projected changes to temperature and precipitation as a result of climate change; and ii) impacts of climate change on the future suitability of several major crops and resulting impacts on production across each of the country's five provinces.

AGRICULTURE IN RWANDA

Rwanda is characterised by a highly productive agriculture sector, which benefits from a bimodal rainfall system. The first rainy season, or Season A, extends from September to December, and the second season, or Season B, starts in March and ends in May (CIAT, 2019)[2]. Rainfed agriculture, practiced by smallholder farmers, accounts for the vast majority of the planted area. Important subsistence crops include roots and tubers (cassava and sweet potato), cereals (maize), legumes such as beans and groundnuts, and banana. Important cash crops include coffee and tea.

[1] https://www.ifad.org/en/web/operations/country/id/Rwanda

[2] https://ccafs.cgiar.org/publications/climate-risk-assessment-selected-value-chain-commodities-rwanda#.Xfog3mQzbIU

SUMMARY RESULTS

The likely effects of climate change are not consistent across the full extent of Rwanda's five provinces or the crops assessed. However, several general observations can be made. For example, all provinces in the study area are predicted to experience increasing temperatures throughout the year, indicated by increased average monthly 'Mean Temperature' as well as average monthly 'Minimum Temperature'. Furthermore, all provinces are predicted to experience an overall decrease in annual and seasonal precipitation between the present day and the 'Mid-Century' future (defined by the period 2040–2069). In addition to the predicted trend of reduced rainfall during the two traditional growing seasons (Season A commencing in September and Season B in March), it is also projected that there will be an increase in monthly rainfall during the months of December and January. These results may be indicative of a delay in the onset of the traditional rainy seasons, or alternatively may indicate that rainy seasons (particularly season A, September-December) may effectively be extended for one to two months. However, despite the latter positive changes, overall the predicted trend is one of decreased annual rainfall on average, with average annual rainfall predicted to decrease from 1,139 mm to 1,066 mm (i.e. a decrease of 73 mm or 6%).

The full study includes analyses of the predicted effect of climate change on various crops, including *inter alia* cereals (maize and sorghum), legumes (common bean and groundnuts), and root crops (cassava and sweet potato). The combined effects of reduced precipitation during the traditional growing seasons and increased temperatures are likely to result in a complex matrix of positive and negative effects on the crops assessed. The annual production of certain crops such as beans, maize and groundnuts is expected to be negatively impacted by increased temperatures and reduced or delayed rainfall, thereby causing a reduction in the extent of suitable production areas as well as reducing the productivity of remaining areas. Conversely, certain crops such as sorghum, cassava and sweet potato are comparatively less affected by the predicted climate changes and may be appropriate alternatives to be promoted in areas where the production of other crops is expected to become marginal.

Production of beans, one of the most important subsistence crops, is predicted to undergo a decrease in annual production ranging from 0.8% in the Western province, up to 8% in the Eastern province. In total, it is estimated that the annual production of beans across all provinces will be reduced by 30 000 tonnes, resulting in total annual costs of climate-related impacts of USD 15.9 million. Production of maize is predicted to decrease by 1.2% in Kigali province up to 4.6% in the Western province. At the household level, the projected decrease in production ranges from 0 kg to 7 kg in the Kigali and Eastern provinces, respectively, equivalent to a total decrease in national maize production of 10 692 tonnes and an annual replacement cost of USD 3.8 million.

In the case of groundnuts, Northern and Western provinces are expected to experience positive effects while the Eastern, Kigali and Southern provinces are predicted to experience negative impacts. In other cases such as sorghum, results indicate that climate change will result in positive impacts across the country, and sweet potatoes are likely to only experience very minor negative changes (with the Southern province being the only negatively impacted province).

There are also several province-specific effects on climate variables and resultant crop suitability that will necessitate the development of tailored local-level adaptation plans and strategies for agricultural development. The climate-related risks to agricultural households in each province are a function of both the impact of climate change on crop production, as well as the adaptive capacities of each community to manage and respond to climate risks. It is important to note that the following analyses are based on consideration of a narrow range of modelled variables and the resultant effects on crop suitability. Consequently, this study cannot account for local-level factors such as differences in performance, climatic suitability and yield potential between local land races or improved cultivars. In addition, the study cannot consider or predict the effect of different cultivation methods and technologies that may be practiced within the study area. Finally, in terms of predicting the likely effects of climate change and resultant risks to crop production, this study cannot account for indirect effects of climate change on crop production, such as increased vulnerability to pests and disease, soil degradation or flooding/waterlogging. However, the study does find that climate change is likely to result in multiple negative effects on smallholder farmers in the study area, through disruption of familiar seasonal trends, increased water and heat stress and a reduced growing season.

METHOD AND APPROACH

The analyses presented in this study are intended to provide an illustrative comparison of the potential effects of future climate change on production of economically important crops, as well as the differential impacts of climate change on agricultural households in each of Rwanda's five provinces. For each of the crops considered in this study (including maize, sorghum, beans, groundnuts, cassava and sweet potato) the relative ***Climate Change Vulnerability (V)*** of crop production is considered at the province level and aims to identify those provinces which are likely to be most or least vulnerable to climate change impacts on the given crop.

The relative vulnerabilities of each province can be expressed as a ***Vulnerability Index*** (***VI***) score, derived by comparison of the relative scale of:

- **Impacts** (**I**) of climate change on crop production (estimated through analysis of climate models and resulting changes to crop suitability); and
- the **Adaptive Capacity (AC)** of agricultural households to respond and adapt to the impacts of climate change (derived through statistical indicators of socio-economic, developmental and agronomic context) in each of Rwanda's five provinces.

Vulnerability is considered to be proportional to the relative size of **I**, and inversely proportional to **AC.** The product of the scores for **AC** and **I** are used to calculate a standardised score for **V**, thereby allowing comparisons between each province and allowing the identification of those provinces and households which are likely to be most vulnerable to climate change impacts on each crop.

IMPACTS

The **Impacts (I)** of climate change on crops were estimated by projecting the likely future changes to Rwanda's climate, and then analysing the effects of those projected climate changes on economically important crops. Firstly, the potential future changes to Rwanda's climate were computed through analysis of 29 General Circulation Models (GCMs) downloaded from the AgMERRA dataset [3], based on the methods described by Ramirez-Villegas et al (2013) [4]. Future climate changes were computed assuming the scenario of 'RCP 8.5' (where 'RCP 8.5' refers to one of four hypothetical scenarios for future global greenhouse gas emissions proposed by the Intergovernmental Panel on Climate Change). This analysis was used to generate predictions of the effect of climate change across Rwanda, comparing the historical baseline (the average climate for the period 1980–2010) to the Mid-Century future (2050, the average climate for the period 2040–2069). In particular, the analysis compares the climatic variables of *Mean Monthly Precipitation* (i.e. the average precipitation for each month), *Monthly Mean Temperature* and *Monthly Minimum Temperature*.

Analyses of current and future crop suitability were generated using the Food and Agriculture Organisation's EcoCrop Suitability model[5] combined with the most recent statistics available for annual crop production and demographics. The EcoCrop model estimates the suitability of a given crop to the defined environmental conditions based on the known preferences of each crop such as: i) minimum, optimum and maximum temperature; ii) minimum, optimum and maximum monthly rainfall; and iii) minimum and maximum growing period. Therefore, EcoCrop defines the area of suitability for a given crop based on whether there are adequate climatic conditions (temperature and precipitation) within the growing season and calculates the climatic suitability of the resulting interaction between rainfall and temperature. Readers are referred to the full project report and the work of Ramirez-Villegas et al (2013) for detailed description of methodology.

A suitability index score, ranging from 0 – 1, indicates the relative suitability of a given area for each of the crops assessed (where a suitability score of 0 is considered to be totally unsuitable, a score of 1 is considered excellent, with a continuous spectrum of marginal, moderate and good suitability

[3] https://data.giss.nasa.gov/impacts/agmipcf/agmerra/
[4] Ramirez-Villegas J, Jarvis A, Laderach P 2013 Empirical approaches for assessing impacts of climate change on agriculture: The EcoCrop model and a case study with grain sorghum. Agricultural and Forest Meteorology 170(15):67-78
[5] https://ecocrop.fao.org/ecocrop/srv/en/home

types in between). In this study, analyses of the distribution of suitable areas for a given crop allows for the estimation of the total suitable production area, as well as the average suitability index score, within each of Rwanda's five provinces. The EcoCrop approach also allows for map-based visualisations of crop suitability zones across the country. The use of colour-coded maps to depict the distribution of various categories of crop suitability index scores can be used to demonstrate the distribution of crop-suitable areas, as demonstrated in Figure 1.

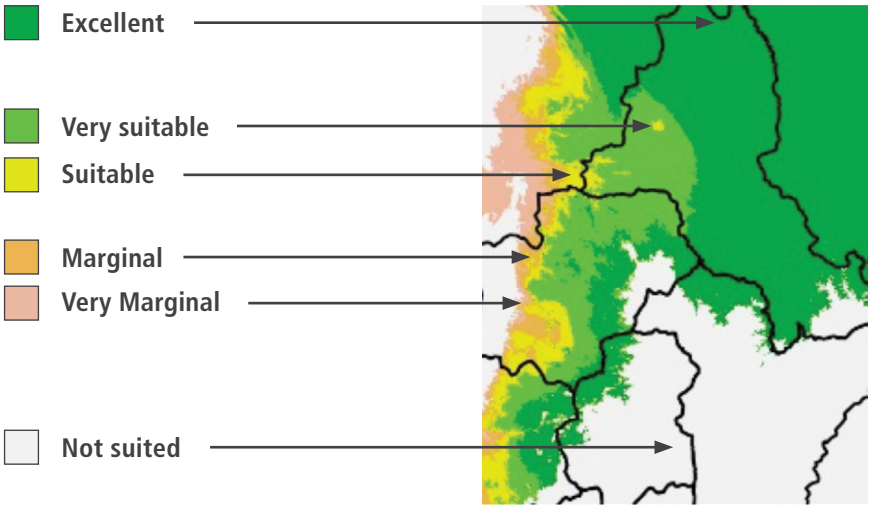
The comparison of maps of 'Historical' and 'Future' distribution of crop suitability can be used to estimate the potential changes to the size and relative productivity of crop-suitable areas. In addition, this approach allows for the identification of specific areas which are likely to undergo positive or negative changes (anomalies) as a result of climate change, and may be used to inform decision-making such as identification of climate-vulnerable areas and value chains to be prioritised for additional support. The potential impacts of climate change on each crop were estimated based on:

- the changes to total suitable area (km^2) and average suitability index score between the historical baseline and 'mid-century' future[6];
- and estimated historical crop production in each province, derived from national agricultural production statistics [7].

The potential impacts of climate change on each crop can be quantified in several ways, for example, in terms of changes to "production per capita", "production per household" and "production per Province". It should be emphasised that no further calibration or validation of EcoCrop analyses was carried out in support of this study and that results should be considered as indicative guidelines only, to inform additional local-level decision-making and further research.

FIGURE 1. DEMONSTRATION EXAMPLE OF THE DISTRIBUTION OF CROP SUITABILITY INDEX.

GENERATED USING ECOCROP



[6] Total suitable area was calculated as the sum of all areas with a suitability index score higher than 0, and average suitability index score is calculated as the average score of all areas with a suitability index score higher than 0

[7] Derived from the 2018 figures reported by the National Institute of Statistics Rwanda (NISR, 2018) Seasonal Agricultural Survey, http://www.statistics.gov.rw/datasource/seasonal-agricultural-survey-2018

ADAPTIVE CAPACITY

Indicators for **Adaptive Capacity (AC)** – the relative ability of agricultural households to respond and adapt to predicted climate change impacts – were derived from the most recent statistics available at the sub-national level. Provincial statistics and indicators were primarily derived from studies undertaken by the Central Statistical Organisation (CSO), technical studies undertaken by the Indaba Agricultural Policy Research Institute (IAPRI), and open-source statistics published on the Rwanda Data Portal [8]. In the case of Rwanda, the indicators used to estimate AC in each Province included

- **Education:** (%literacy rate)
- **Access to agricultural information** (% households owning a radio, % households that have received extension services)
- **Access to alternative sources of income:** (% employment rate)
- **Adoption of improved agricultural practices:** (organic fertiliser use, pesticide use; use of improved seeds).

The national statistics collected to assess AC – which are summarised in the Appendix (Table A.1) – were used to calculate an average AC score for each Province. The indicator category **'Adoption of improved agricultural practices'** was assigned a weighting of 50% towards the final **AC** score, and the remaining 50% was contributed equally by the remaining indicator categories. These are presented in Table 1.

While the **AC** scores generated are fairly closely clustered and differences are relatively small, rankings indicate that smallholder farmers in the Northern and Western provinces have the highest overall capacities to respond to climate change impacts (ranking 1st and 2nd, respectively). Kigali and the Eastern province have the lowest overall **AC** scores (ranking 4th and 5th, respectively) and therefore are anticipated to be least able to respond or adapt to climate change-related impacts. This is expected of the Eastern province as it is largely rural, characterised by subsistence or small-scale agriculture, whereas the results are surprising for Kigali province, which is more developed and with better access to education and technology (where they score highly). Reasons for the low score in Kigali province need further investigation.

TABLE 1. RANKED ADAPTIVE CAPACITY (AC) INDICATOR SCORES FOR ALL PROVINCES OF RWANDA

	Adaptive capacity Indicator category					
	Adoption of improved agricultural practices	Access to agricultural information	Education	Alternative sources of income	**Adaptive capacity score**	**Adaptive capacity rank**
Contribution to index	50%	17%	17%	17%		
Eastern	16	50	69.4	85.4	42.1	**5**
Kigali	18.2	50.4	86.6	82.4	45.7	**4**
Northern	28	53.4	71.4	90.3	49.8	**1**
Southern	25.2	49.3	68.8	85.9	46.6	**3**
Western	26.5	50.6	68	85.9	47.3	**2**

[8] Statistics were derived from 2017 and 2018 census studies produced by Rwanda's National Institute of Statistics: Agricultural Household Survey, http://statistics.gov.rw/publication/agricultural-household-survey-2017; and Labour Force Survey Report, http://statistics.gov.rw/publication/labour-force-survey-report-december-2018

CLIMATE PROJECTIONS

PROJECTED CHANGES TO TEMPERATURE IN RWANDA BY 2050

The predicted changes in Mean Monthly Temperature (TMean) during the period from 'Historical' to 'Future 2050' timepoints indicate that climate change will result in consistent increases in Mean Temperature across spatial and temporal dimensions in Rwanda. A common prediction across each of the country's five provinces is that TMean will increase in all provinces during the period from 'Historical' to 'Mid-Century' timepoints by at least 1.7°C. The hottest months of August and September are predicted to increase by 2.1°C, relative to a Historical average of 21°C. Similar increases of 1.7–2.2°C are predicted for all other months of the year.

The overall effect of these increases in TMean and TMin is likely to result in complex impacts on the agricultural sector, particularly when considered in combination with the predicted decreases in precipitation. The large increases in temperature (1.7–2.1°C) in the months of October–December will increase crop water demand and evapotranspiration losses of water from agricultural soils, coinciding with the reduced rainfall predicted for the same months. This effect is likely to increase the risks of crop failure as a result of inadequate or erratic rainfall during the establishment of rainfed crops, particularly for climate sensitive or marginal crops such as maize and horticultural/vegetable crops such as tomatoes and peppers. Furthermore, the increased average temperatures are likely to include increased frequency or severity of heat waves and unusually hot days, further contributing to evapotranspirative losses of water and crop stress.

TABLE 2. PROJECTED INFLUENCE OF CLIMATE CHANGE ON MEAN MONTHLY TEMPERATURE (°C) IN RWANDA AT HISTORICAL AND MID-CENTURY PERIODS, AND MONTHLY ANOMALIES BETWEEN THE TWO TIME PERIODS [9]

Tmean (°C)	**MONTH**											
	J	F	M	A	M	J	J	A	S	O	N	D
Historical	20.1	20.4	20.3	19.9	19.9	19.8	20.0	20.9	21.0	20.5	19.9	20.0
Future	21.9	22.3	22.1	21.7	21.8	21.9	22.2	23.1	23.1	22.5	21.6	21.8
Anomaly	**1.8**	**1.9**	**1.8**	**1.8**	**1.9**	**2.1**	**2.2**	**2.1**	**2.1**	**2.0**	**1.7**	**1.8**

[9] Historical temperature based on the average of the period 1980-2010, and projected Mid-Century temperature for the period 2040-2069. Anomalies are defined as the total change between Historical and Mid-Century projections

CLIMATE – PROJECTED CHANGES TO RAINFALL IN RWANDA BY 2050

The predicted changes in mean monthly precipitation from the historical baseline to the mid-century (2050) future indicate that climate change will result in complex changes in rainfall across provinces and months (see Table 3). Province-level summaries of predicted monthly changes in precipitation can be found in the supplementary Appendix.

A common prediction across each of the country's five provinces is that total annual precipitation will be reduced in all provinces during the period from baseline to Mid-Century timepoints. The total rainfall received during the months of September to December at the onset of the first, long rainy season is predicted to be reduced from 465 to 443 mm (total reduction of rainfall of 22 mm). Similarly, total rainfall at the onset of the shorter second rainy season in the months of March, April and May is predicted to be reduced from 400 to 360mm (total reduction of rainfall of 40mm).

An additional effect of climate change predicted by these analyses is the increase in monthly rainfall during the months of December and January. These results may be indicative of a delay in the onset of the traditional rainy seasons, or alternatively may indicate that rainy seasons (particularly season A, September-December) may effectively be extended for one to two months. It should be noted that these effects are likely to vary on an interannual basis as well as spatially within each season, and the consequent impacts on agricultural activities cannot be predicted with certainty. In some cases, the average reduction in monthly rainfall, notably during the months of September-October may result in inadequate rainfall to support effective establishment of crops during the period which is traditionally associated with the start of each growing season. Alternatively, the positive anomalies (i.e. predicted increases) in monthly rainfall in the months of December – January may indicate an extension in the duration of the rainy season A, thereby providing farmers with the option to extend or stagger the timing of crop establishment.

These analyses indicate that climate change may delay the onset of rainfall relative to the traditional agricultural calendar, in turn resulting in changes to the timing of various agricultural activities such as field preparation and sowing of seed. Both of the rainfed agricultural growing seasons are characterised by monthly rainfall deficits which may result in fundamental changes to local crop choices and agricultural practices by the year 2050. Drought-sensitive crops such as maize are likely to be increasingly unreliable or poor in yield, which will be further exacerbated by predicted increases in temperature.

TABLE 3. PROJECTED INFLUENCE OF CLIMATE CHANGE ON MEAN MONTHLY PRECIPITATION (MM/MONTH) IN RWANDA AT HISTORICAL AND MID-CENTURY PERIODS, AND MONTHLY ANOMALIES BETWEEN THE TWO TIME PERIODS [10].

MM/MONTH	MONTH												TOTAL
	J	F	M	A	M	J	J	A	S	O	N	D	
Historical	100.3	100.9	135.0	154.5	110.3	23.0	14.6	36.0	85.6	124.0	148.2	107.0	1139.4
Future	101.9	99.7	128.9	143.9	87.1	17.7	13.0	31.0	75.7	110.1	146.9	110.4	1066.3
Anomaly	**+1.7**	**-1.1**	**-6.1**	**-10.5**	**-23.2**	**-5.3**	**-1.7**	**-5.0**	**-9.9**	**-14.0**	**-1.3**	**+3.4**	**-73.0**

[10] Historical precipitation based on the average of the period 1980-2010, and projected Mid-Century precipitation for the period 2040-2069. Anomalies are defined as the total change between Historical and Mid-Century projections. Province-level summaries of predicted monthly changes in precipitation can be found in the supplementary Appendix).

CLIMATE CHANGE AND ITS EFFECT ON BEANS

BROAD CONTEXT

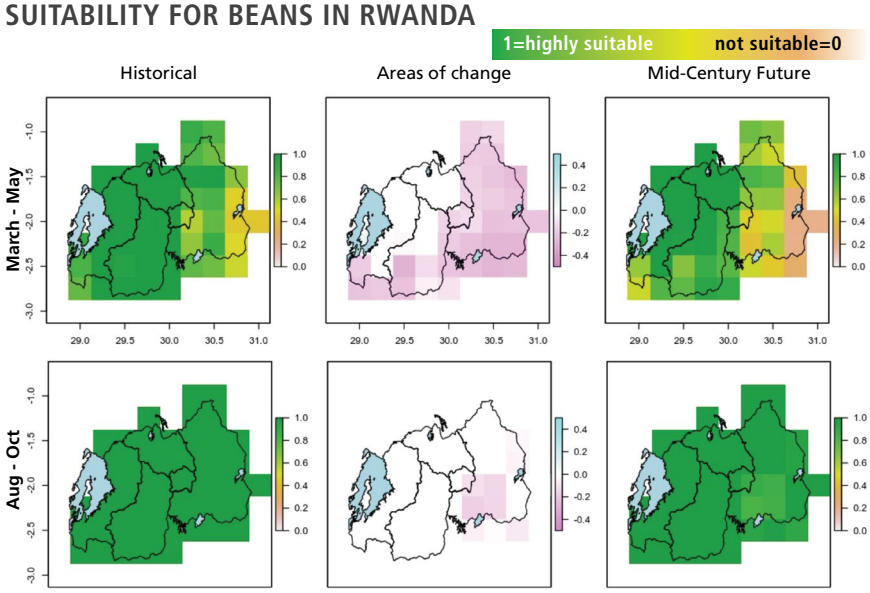
Beans are widely grown as a staple subsistence crop across most of Rwanda's provinces, where the entire country is considered to be highly suitable for bean production, in both rainy seasons.

Climate change is projected to result in minor negative impacts on the suitability for bean production. The southern parts of the Eastern and Kigali provinces will experience decreases in suitability index score in the first (September) rainy season. The second rainy season in March is likely to be affected by relatively widespread reductions in suitability, resulting in decreases to productivity of 1.7 – 14%, with large parts of the Eastern province becoming increasingly marginal for beans.

PRODUCTION OF BEANS IN RWANDA[11].

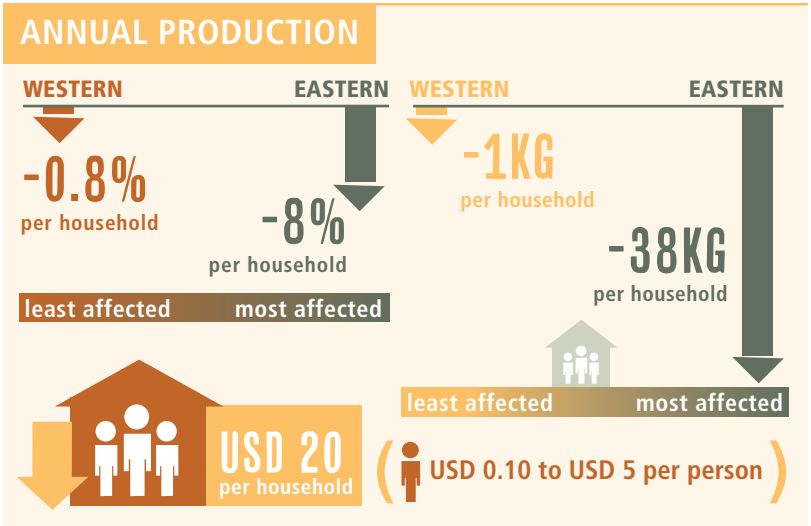
REGION	PRODUCTION AREA		ANNUAL PRODUCTION	
	TOTAL (HA)	% NATIONAL TOTAL	TOTAL (TONNES)	% NATIONAL TOTAL
Eastern	218,549	40.2	315,999	43.4
Kigali	16,012	2.9	20,816	2.9
Northern	103,622	19.1	191,798	26.4
Southern	135,781	25.0	138,630	19.1
Western	69,779	12.8	60,422	8.3
Total	**543,743**		**727,665**	

PROJECTED EFFECT OF CLIMATE CHANGE ON DISTRIBUTION OF SUITABILITY FOR BEANS IN RWANDA



HOUSEHOLD LEVEL IMPACTS

It is predicted that households will experience a decrease in annual production ranging from 0.8 % in the Western province, up to 8% in the Eastern province. In terms of the total impact of climate change on the annual production of agricultural households, the predicted decrease in annual production may range from 1 kg per household in the Western province, up to 38 kg per household in the Eastern province. The costs of reduced production of beans are estimated to range from USD 0.10 to USD 5 per person, or, up to USD 20 per household[12].



[11] Derived from the 2018 figures reported by the National Institute of Statistics Rwanda (NISR, 2018), Seasonal Agricultural Survey, http://www.statistics.gov.rw/datasource/seasonal-agricultural-survey-2018

[12] Prices obtained from https://fews.net/sites/default/files/documents/reports/MONTHLY%20PRICE%20WATCH%20with%20ANNEX_November2019_FINAL.pdf US Dollar: Rwandan Franc exchange rate was estimated as 0.0011. Average market price for beans is approximately USD 0.52 per kg

PROVINCE AND NATIONAL-LEVEL IMPACTS

At the province level, the total reduction in annual production of beans is projected to range from 469 tonnes in the Western province, the least affected, to 24 866 tonnes in the Eastern province. In total, it is estimated that the annual production of beans across all provinces will be reduced by 30 605 tonnes. At the provincial scale, it is anticipated that the greatest cost for purchase of replacement food will be for the Eastern Province (USD 12.9 million). At a national scale, the total annual costs of climate-related impacts on beans is estimated to be USD 15.9 million.

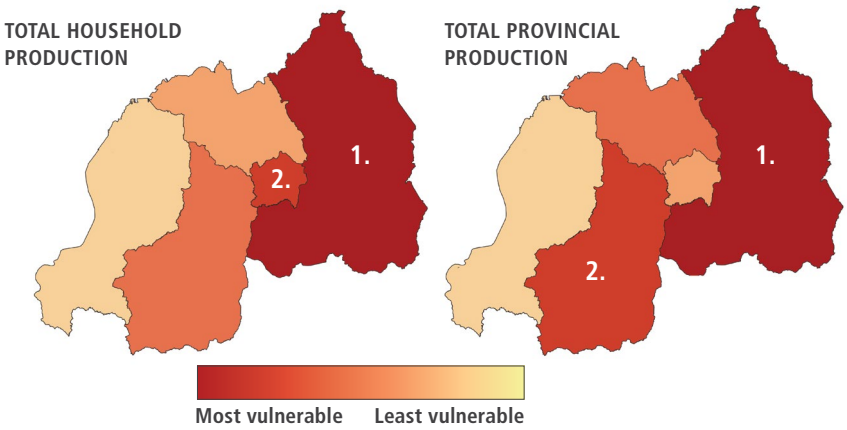
Total loss of annual production **30 605** tonnes

Total replacement cost **USD 15.9** million

CLIMATE VULNERABLE PROVINCES AND HOUSEHOLDS

At the household level, the provinces which will experience the most severe negative impacts on %change to production per capita (i.e. decreased production relative to average historical production) are the Eastern (1) and Kigali (2) provinces. At the provincial-level, the most severe negative impacts on total production per administrative province are the Eastern (1) and Southern (2) provinces.

MOST VULNERABLE PROVINCES, BASED ON CHANGES TO:



KEY FINDINGS AND RECOMMENDATIONS

- All of Rwanda's provinces will experience decreased production of beans, particularly at the onset of rainy season B in March.
- The Eastern province is likely to be the worst affected.
- Total replacement costs incurred by households to replace lost food production is estimated to be up to USD 15.9 million per year.
- Estimated decrease in annual production of 30,000 tonnes, total replacement costs incurred by households up to USD 15.9 million per year.
- Western, Central, Northern and Kigali provinces will maintain some areas of adequate suitability.

Recommended actions: additional investments in research and development to identify locally appropriate cultivars, further promotion of diverse alternative legumes such as groundnuts.

CLIMATE CHANGE AND ITS EFFECT ON CASSAVA

BROAD CONTEXT

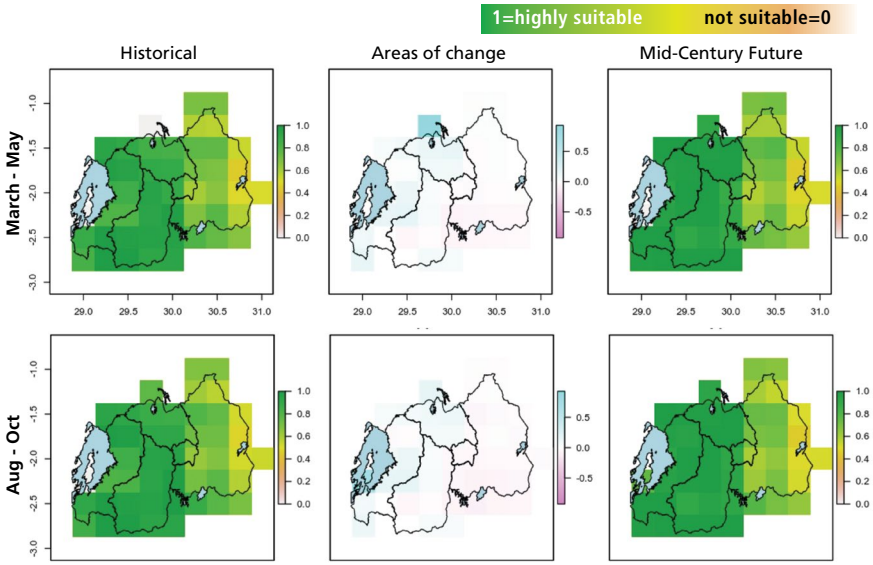
Cassava is widely grown as a subsistence crop across all of Rwanda's provinces, with widespread areas of good or excellent suitability. The only regions which appear to be less well-suited to cassava production are the eastern borders of the country.

Climate change will likely result in very slight decreases in suitability in the Eastern and Kigali provinces (resulting in decreases in productivity ranging from -0.6 to -3.1%.) and slight increases in the Northern, Western and Southern provinces. This increase in suitability in the Northern and Western parts of the country contributes to a very minor increase in the total spatial extent of area suitable for cassava production. The entire spatial extent of Rwanda is predicted to remain suitable for production of cassava during both rainy seasons.

PRODUCTION OF CASSAVA IN RWANDA[13].

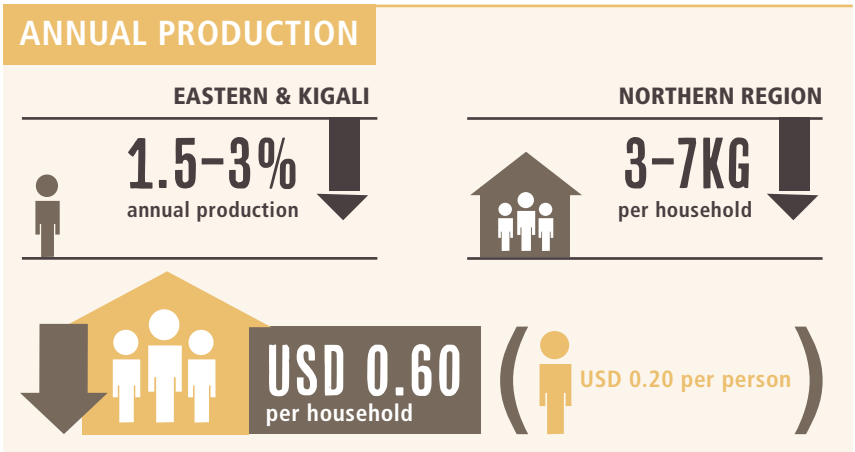
REGION	PRODUCTION AREA		ANNUAL PRODUCTION	
	TOTAL (HA)	% NATIONAL TOTAL	TOTAL (TONNES)	% NATIONAL TOTAL
Eastern	134,015	17.4	303,674	14.6
Kigali	9,791	1.3	23,761	1.1
Northern	34,322	4.5	77,566	3.7
Southern	112,038	14.6	387,878	18.6
Western	94,062	12.2	247,923	11.9
Total	**384,228**		**1,040,802**	

PROJECTED EFFECT OF CLIMATE CHANGE ON DISTRIBUTION OF SUITABILITY FOR CASSAVA IN RWANDA



HOUSEHOLD LEVEL IMPACTS

Eastern and Kigali provinces are the only provinces predicted to experience negative impacts on cassava production, where households are projected to experience a decrease of 1.5-3% in annual production. This change in annual production is equivalent to a deficit of 3-7 kg per household. The cost of reduced production of cassava in the Eastern province, the worst affected of Rwanda's provinces, is estimated to be USD 0.2 per person, or, up to USD 0.6 per household.



The remaining provinces are predicted to benefit from very small increases to the average suitability index score and resultant productivity. These results must not be interpreted as a strong prediction that annual production will increase as a result of climate change. Rather, these results suggest that those provinces which benefit from increased suitable area are unlikely to be impacted severely by negative effects of climate change, but may not necessarily be able to benefit fully from the predicted increase of suitability.[14]

[13] Derived from the 2018 figures reported by the National Institute of Statistics Rwanda (NISR, 2018), Seasonal Agricultural Survey, http://www.statistics.gov.rw/datasource/seasonal-agricultural-survey-2018

[14] Prices obtained from https://allafrica.com/stories/201909250360.html. US Dollar: Rwandan Franc exchange rate was estimated as 0.0011. Average market price is approximately USD 0.09 per kg.

PROVINCE AND NATIONAL-LEVEL IMPACTS

In terms of the potential impact on total provincial production, estimated impacts on Eastern and Kigali provinces are 4,471 and 715 tonnes, respectively. At a national scale, the total annual costs of climate related impacts on cassava is estimated to be USD 484 895.

Total loss of annual production

5186 tonnes

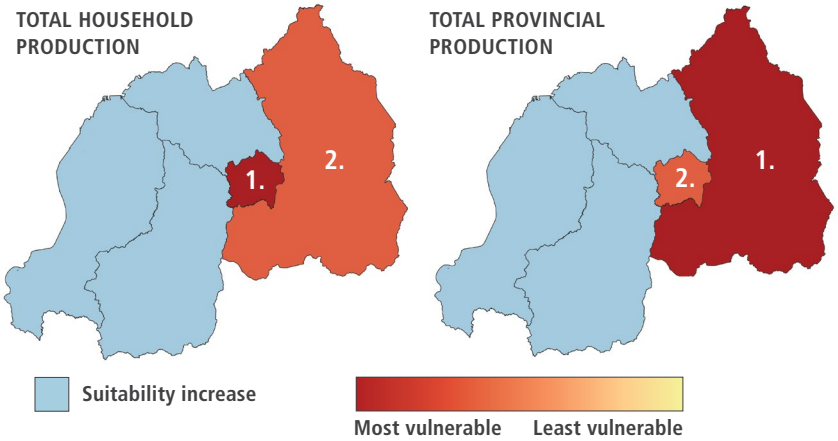
Total replacement cost

USD 484 895

CLIMATE VULNERABLE PROVINCES AND HOUSEHOLDS

At the household level, the provinces which will experience the most severe negative impacts on production per capita (i.e. decreased production relative to average historical production) are Kigali (1) and Eastern (2) provinces. At the provincial-level, the most severe negative impacts on total production per administrative province are the Eastern (1) and Kigali (2) provinces. Cassava production in all the remaining provinces (Northern, Southern and Western) is predicted to experience net benefits as a result of increased suitable area.

MOST VULNERABLE PROVINCES, BASED ON CHANGES TO:



KEY FINDINGS AND RECOMMENDATIONS

- Most of Rwanda is unlikely to experience severe negative impacts on cassava production.
- Eastern and Kigali provinces are the only provinces that are likely to experience decreased production potential.
- The total loss of national production resulting from climate change is estimated to be 5,100 tonnes per annum, equivalent to a replacement cost of USD 485,000 per year.
- Cassava is a flexible crop, allowing roots and leaves to be harvested throughout the year according to household needs.
- The continued distribution of suitable areas for cassava suggests that this crop is likely to remain a useful option for climate-resilient farming systems.

Recommended actions: increased access to quality, virus-free planting material of improved varieties; increased access to facilities and equipment for processing fresh cassava; improved capacity of farmers to monitor and respond to common pests and diseases.

CLIMATE CHANGE AND ITS EFFECT ON GROUNDNUT

BROAD CONTEXT

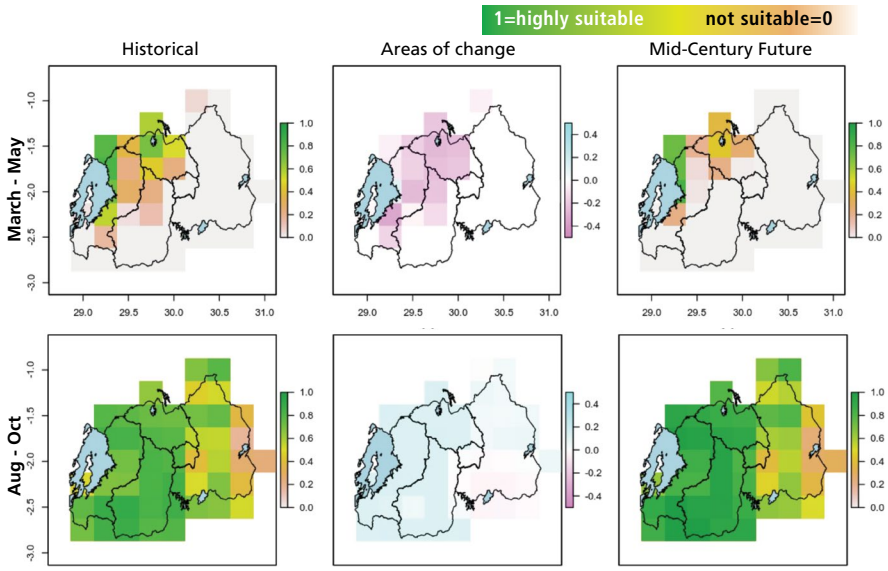
Groundnuts are grown as a subsistence crop across all of Rwanda's provinces with widespread areas of good or excellent suitability in rainy season A, and areas of moderate or good suitability in North, Eastern and portions of Southern province in rainy season B.

Climate change may result in complex impacts on groundnut production, where analyses indicate that all provinces will experience decreases in productivity at the onset of rainy season B (ranging from -0.7 to –100%) and increases in productivity at the onset of the rainy season A (ranging from 3.6 to 8.9%) and reduced spatial extent of suitable areas at the onset of rainy season B. Most of the country is projected to remain suitable to highly suitable for groundnuts at the onset of rainy season A.

PRODUCTION OF GROUNDNUTS IN RWANDA[15].

REGION	PRODUCTION AREA		ANNUAL PRODUCTION	
	TOTAL (HA)	% NATIONAL TOTAL	TOTAL (TONNES)	% NATIONAL TOTAL
Eastern	33,137	36.5	14,859	36.0
Kigali	940	1.0	415	1.0
Northern	1,026	1.1	881	2.1
Southern	9,494	10.4	3,892	9.4
Western	836	0.9	619	1.5
Total	**45,433**		**20,666**	

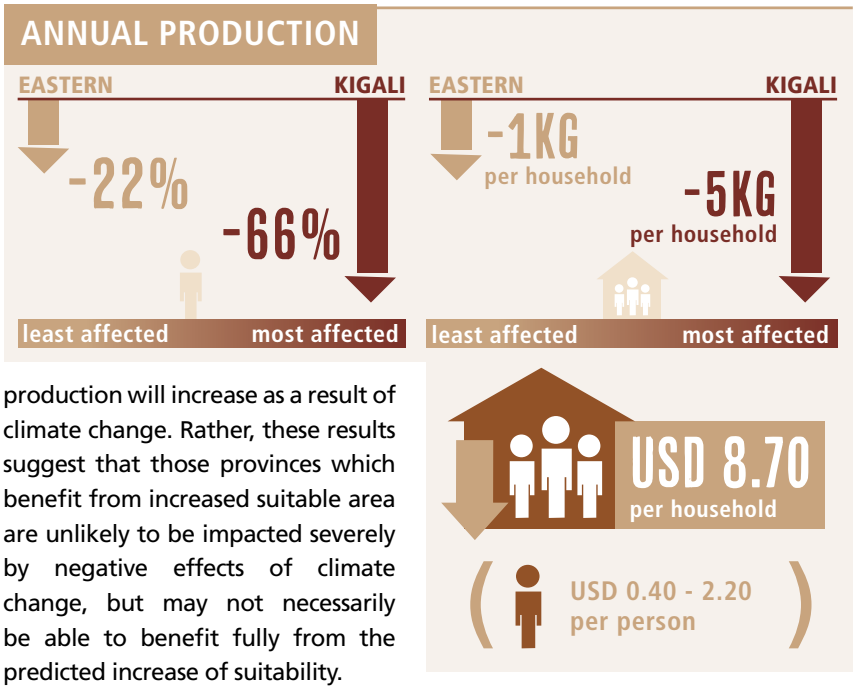
PROJECTED EFFECT OF CLIMATE CHANGE ON DISTRIBUTION OF SUITABILITY FOR GROUNDNUTS IN RWANDA



HOUSEHOLD LEVEL IMPACTS

The Eastern, Southern and Kigali provinces are predicted to experience small negative impacts on groundnut production, where households are projected to experience a decrease of 22% (Eastern) to 66% (Kigali) of annual production. These changes in annual production are equivalent to an annual deficit of 1-5kg per household. The costs of reduced production of groundnuts are estimated to range from USD 0.40 to USD 2.20 per person, or, up to USD 8.7 per household[16].

The Northern and Western provinces are predicted to benefit from minor increases to the average suitability index score and resultant productivity. These results must not be interpreted as a strong prediction that annual production will increase as a result of climate change. Rather, these results suggest that those provinces which benefit from increased suitable area are unlikely to be impacted severely by negative effects of climate change, but may not necessarily be able to benefit fully from the predicted increase of suitability.



[15] Derived from the 2018 figures reported by the National Institute of Statistics Rwanda (NISR, 2018), Seasonal Agricultural Survey, http://www.statistics.gov.rw/datasource/seasonal-agricultural-survey-2018

[16] Prices obtained from https://allafrica.com/stories/201805010029.html. US Dollar: Rwandan Franc exchange rate was estimated as 0.0011. The average market price is approximately USD 1.76 per kg.

PROVINCE AND NATIONAL-LEVEL IMPACTS

In terms of total annual production of groundnuts within each province, it is predicted that the Eastern and Southern provinces, the two worst-affected provinces, will experience a decrease in annual production of 3,204 and 1,503 tonnes respectively. In total, it is estimated that the annual production of groundnuts across the negatively affected provinces will be reduced by 4,980 tonnes. The greatest cost for purchase of replacement food will be for the Eastern Province (USD 5.6 million). At a national scale, the total annual costs of climate-related impacts on groundnuts is estimated to be USD 8.8 million.

Total loss of annual production

4 980 tonnes

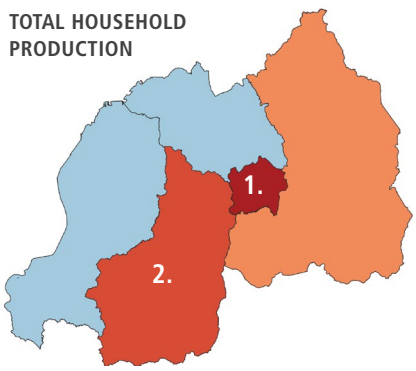
Total replacement cost

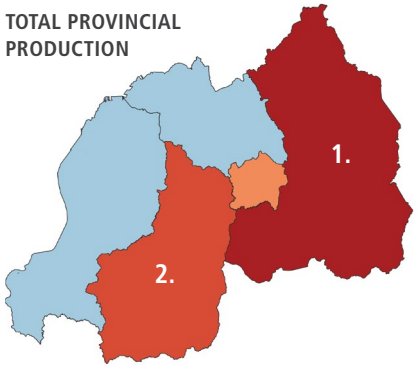
USD 8.8 million

CLIMATE VULNERABLE PROVINCES AND HOUSEHOLDS

At the household level, the provinces which will experience the most severe negative impacts on %change to production per capita (i.e. decreased production relative to average historical production) are the Kigali (1) and Southern (2) provinces. At the provincial-level, the most severe negative impacts on total production per administrative province are the Eastern (1) and Southern (2) provinces.

MOST VULNERABLE PROVINCES, BASED ON CHANGES TO:





Most vulnerable — Least vulnerable

Suitability increase

KEY FINDINGS AND RECOMMENDATIONS

- Rwanda will likely experience minor or moderate decreases in production of groundnut during rainy season B (March), particularly in Eastern, Kigali and Southern provinces.
- The Western and Northern provinces are unlikely to experience severe negative impacts to production of groundnuts as a result of climate change.
- All provinces continue to be characterised by widespread areas of suitability for groundnuts in season A.
- The total loss of national production resulting from climate change is estimated to be 4,980 tonnes per annum, equivalent to a replacement cost of USD 8.8 million per year.
- Despite the predicted negative impacts, the continued extensive distribution of suitable areas for groundnut production suggests that this crop is likely to remain a useful option for climate-resilient farming systems.

Recommended actions: promote within diversified, multi-crop and intercrop combinations; research, develop and promote locally-adapted and drought resilient varieties; invest in post-harvest processing facilities.

CLIMATE CHANGE AND ITS EFFECT ON MAIZE

BROAD CONTEXT

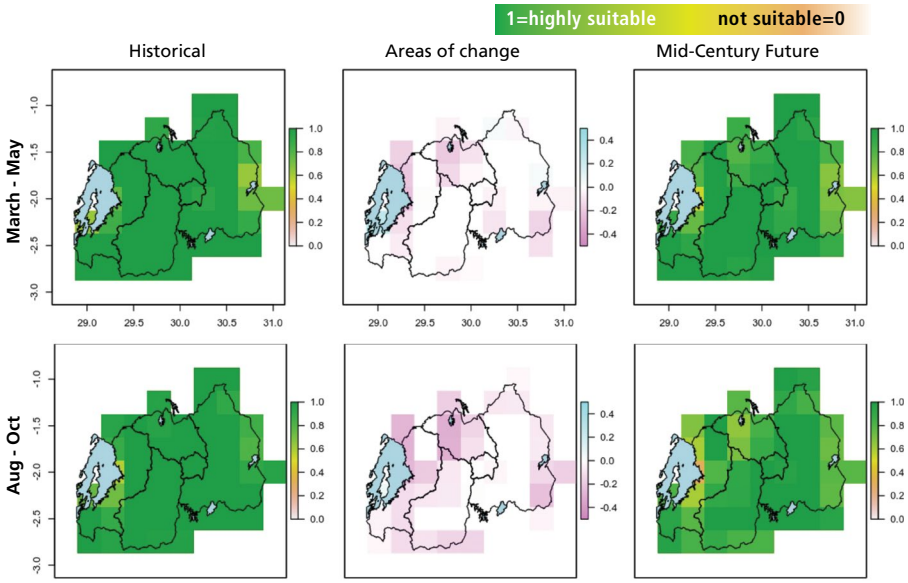
Maize is the main cereal crop of Rwanda. It is characterised by widespread areas of suitability and is planted in both rainy seasons.

All provinces are predicted to undergo decreases to average suitability index score and resultant negative changes to productivity in both rainy seasons. The Northern province is expected to experience the greatest decreased productivity in both rainy seasons. However, despite these negative changes, the total suitable area for production of maize is expected to remain unchanged across all provinces. All provinces are expected to continue to be characterised by excellent suitability on average.

PRODUCTION OF MAIZE IN RWANDA[17].

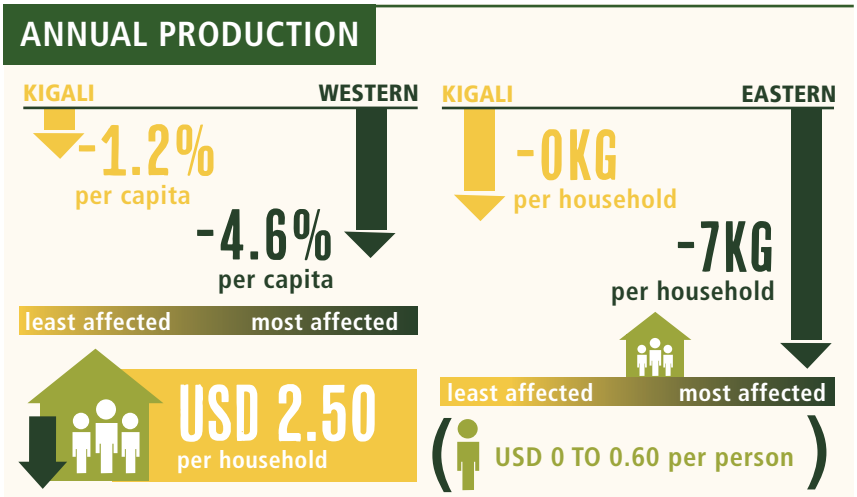
REGION	PRODUCTION AREA		ANNUAL PRODUCTION	
	TOTAL (HA)	% NATIONAL TOTAL	TOTAL (TONNES)	% NATIONAL TOTAL
Eastern	166,918	28.6	247,575	31.0
Kigali	7,424	1.3	7,715	1.0
Northern	40,548	6.9	53,460	6.7
Southern	37,391	6.4	42,258	5.3
Western	39,935	6.8	48,614	6.1
Total	**292,216**		**399,622**	

PROJECTED EFFECT OF CLIMATE CHANGE ON DISTRIBUTION OF SUITABILITY FOR MAIZE IN RWANDA



HOUSEHOLD- AND NATIONAL-LEVEL IMPACTS

The total % change of annual production of maize per capita is predicted to range from a loss of 1.2% in Kigali province up to 4.6% in the Western province. At the household level, the projected decrease in production ranges from 0 kg to 7 kg in the Kigali and Eastern provinces, respectively. The costs of reduced production of maize are estimated to range from USD 0 to USD 0.60 per person, or, up to USD 2.5 per household[18].



[17] Derived from the 2018 figures reported by the National Institute of Statistics Rwanda (NISR, 2018), Seasonal Agricultural Survey, http://www.statistics.gov.rw/data-source/seasonal-agricultural-survey-2018

[18] Prices obtained from https://fews.net/sites/default/files/documents/reports/MONTHLY%20PRICE%20WATCH%20with%20ANNEX_November2019_FINAL.pdf. US Dollar: Rwandan Franc exchange rate was estimated as 0.0011. Average market price is approximately USD 0.36 per kg.

PROVINCE AND NATIONAL-LEVEL IMPACTS

At the provincial level, the cumulative deficit in production of maize ranges from 92 tonnes in Kigali province up to 4576 tonnes in the Eastern province (resulting in replacement costs of USD 1.6 million). At the national level, the total decrease in maize production is equivalent to 10 692 tonnes, resulting in annual replacement costs for lost production of USD 3.8 million.

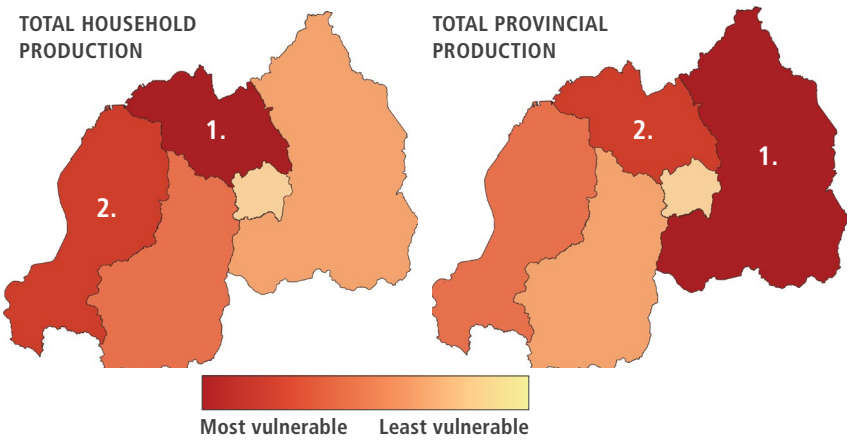
Total loss of annual production **10 692** tonnes

Total replacement cost **USD 3.8** million

CLIMATE VULNERABLE PROVINCES AND HOUSEHOLDS

At the household level, the provinces which will experience the most severe negative impacts on %change to production per capita (i.e. decreased production relative to average historical production) are the Northern (1) and Western (2) provinces. At the provincial-level, the most severe negative impacts on total production per administrative province are the Eastern (1) and Northern(2) provinces.

MOST VULNERABLE PROVINCES, BASED ON CHANGES TO:

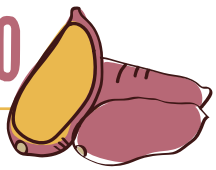


KEY FINDINGS AND RECOMMENDATIONS

- The negative effects of climate change on maize are expected to be minor or moderate across most of Rwanda's provinces.
- Most of Rwanda is likely to remain widely suitable for maize production.
- The Eastern and Northern provinces are predicted to experience the greatest decreases in maize production, up to 10,700 tonnes or a replacement cost to households of USD 3.8 million.
- Maize is likely to remain well-suited for Rwanda's climate by the mid-century future.
- Results for sorghum (not included in this report) indicate minor increases in suitability - all provinces are expected to be characterised by excellent suitability and therefore this crop is likely to be a useful climate-resilient alternative to maize.

Recommended actions include: i) identify and increase access to the most locally appropriate cultivars to be promoted, notably including fast-maturing varieties; ii) increase technical support and assistance for farmers to adopt new practices for climate resilience and management of climate risks; and iii) promote the adoption of alternative, climate-resilient crops such as sorghum and millet.

CLIMATE CHANGE AND ITS EFFECT ON SWEET POTATO



BROAD CONTEXT

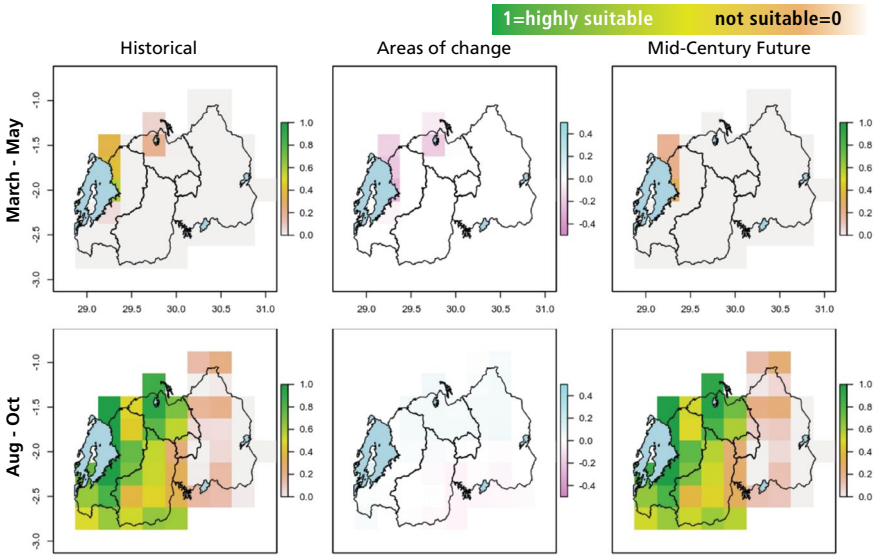
Sweet potato is grown as a subsistence crop across most of Rwanda's provinces with widespread areas of good or excellent suitability in rainy season A, and areas of moderate or good suitability in Northern and Eastern provinces during rainy season B.

Rwanda is likely to experience a mix of positive, neutral and small negative changes to suitability for sweet potato production. At the onset of rainy season A, Kigali and Southern provinces may experience some minor decreases to suitability while the other provinces may benefit from small increases. Rainy season B, which is characterised by comparatively moderate baseline suitability, is predicted to experience decreases in all provinces, to the extent that all provinces except Western province will become completely unsuitable for sweet potato.

PRODUCTION OF BEANS IN RWANDA[19].

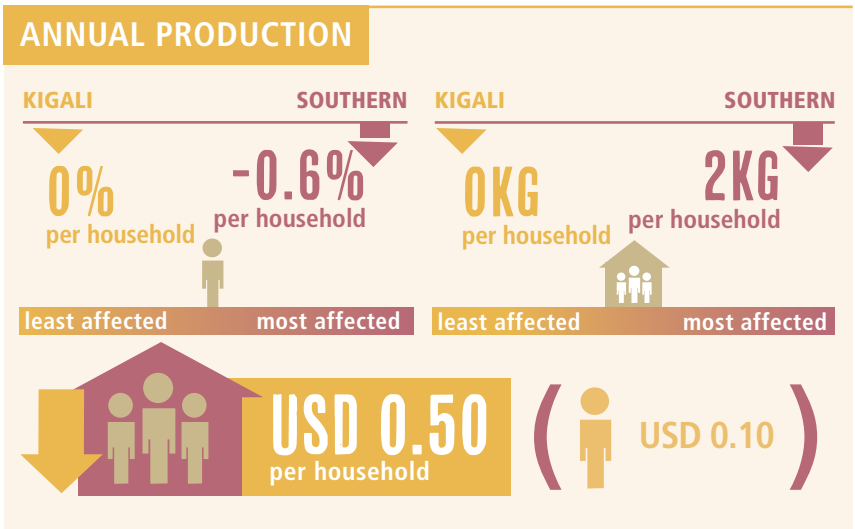
REGION	PRODUCTION AREA		ANNUAL PRODUCTION	
	TOTAL (HA)	% NATIONAL TOTAL	TOTAL (TONNES)	% NATIONAL TOTAL
Eastern	14,021	8.0	72,020	11.2
Kigali	1,592	0.9	87,352	13.6
Northern	20,351	11.6	10,461	1.6
Southern	26,666	15.2	7,001	1.1
Western	25,086	14.3	144,233	22.5
Total	**87,716**		**321,067**	

PROJECTED EFFECT OF CLIMATE CHANGE ON DISTRIBUTION OF SUITABILITY FOR BEANS IN RWANDA



HOUSEHOLD AND PROVINICAL LEVEL IMPACTS

The Southern province is the only province that predicted to experience negative impacts on sweet potato production, where households are projected to experience a decrease of 0.6%. The changes in Kigali province are too small to have an impact at the household or provincial levels. These changes in annual production in Southern province are equivalent to a deficit of 2 kg at the household level, resulting in a replacement cost for lost production of USD 0.10 per person, or USD 0.50 per household[20].



[19] Derived from the 2018 figures reported by the National Institute of Statistics Rwanda (NISR, 2018), Seasonal Agricultural Survey, http://www.statistics.gov.rw/datasource/seasonal-agricultural-survey-2018

[20] Prices obtained from https://allafrica.com/stories/201805010029.html. US Dollar: Rwandan Franc exchange rate was estimated as 0.0011. The average market is approximately USD 0.28 per kg.

In total, the predicted decrease of production of sweet potato from Southern province is relatively minor, equivalent to 1,178kg and resulting in total replacement costs of USD 323 833 per year.

Total loss of annual production

1 178 kg

Total annual cost

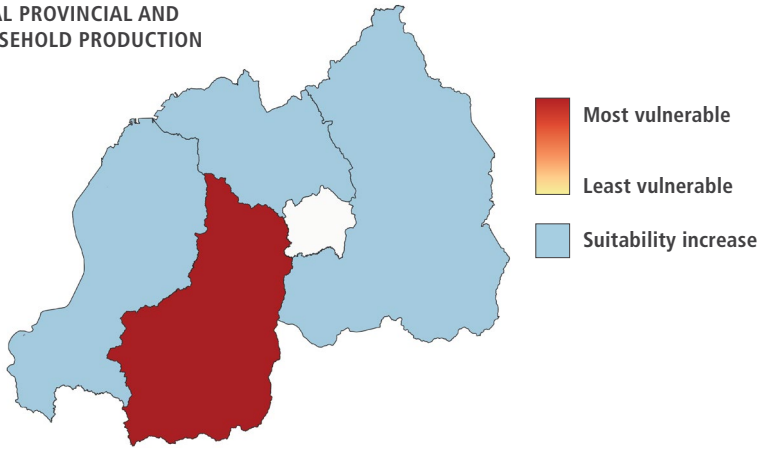
USD 323 833

CLIMATE VULNERABLE PROVINCES AND HOUSEHOLDS

The Southern province is likely to be the only province that experiences negative impacts on sweet potato production in both rainy seasons, and is therefore likely to be the most vulnerable to climate change impacts on sweet potato production, both at the household-level and at the provincial-level.

MOST VULNERABLE PROVINCES, BASED ON CHANGES TO:

TOTAL PROVINCIAL AND HOUSEHOLD PRODUCTION



KEY FINDINGS AND RECOMMENDATIONS

Southern province is expected to undergo decreased production potential for sweet potato.

Western and Northern provinces are unlikely to experience severe negative impacts on the production of sweet potato as a result of climate change, and continue to be characterised by moderate-to-good suitability at the onset of rainy season A (September).

Sweet potato is likely to be a useful option for climate-resilient farming systems, particularly in Western and Northern provinces.

SUMMARY OF FINDINGS, RECOMMENDATIONS, ADAPTATION STRATEGIES AND CLIMATE-RESILIENT ALTERNATIVES FOR SMALLHOLDER FARMERS

The summarised findings above indicate that several important staple crops – notably beans, groundnut and maize – are predicted to experience moderate decreases in production. Consequently, it is strongly recommended that initiatives related to climate change adaptation, food security and enhanced agricultural production include careful consideration of strategies to increase the resilience of these three crops. Simultaneously, analysis of the future suitability of sorghum, cassava and sweet potato indicate that Rwanda may continue to be characterised by widespread areas of good or excellent suitability by the Mid-Century future.

In the case of maize, the results support the case for development and promotion of fast-growing, early-maturing varieties to be disseminated as widely as possible. The risk of reduced production of all maize varieties can be partly offset by continued promotion of crop diversification, including intercropping and multi-crop approaches that include diverse legumes and alternative cereals such as sorghum.

In the case of beans, the results indicate a moderate reduction of production between the current baseline period and the mid-century future, particularly in Season B. Despite this predicted negative trend, beans and other leguminous crops are still expected to be a useful component of future strategies to adapt smallholder agriculture to climate change in Rwanda. The crop is already widely grown and eaten, can be incorporated into diverse inter-cropping and crop rotation strategies with other staple crops, and contributes positively to soil fertility. The potential risk of negative impacts of climate change on beans can partly be offset by promoting the adoption of a diversity of bean cultivars as well as additional legume species such as groundnuts.

In the case of groundnuts, climate change is predicted to result in negative effects on production in the Eastern, Kigali and Southern provinces in Season B but with possible positive effects in the Northern and Western provinces. Although these three provinces are predicted to undergo decreases in annual production, they continue to be characterised by widespread areas of suitability for groundnuts in season A. As a result, groundnuts are likely to be a useful option for climate-resilient farming systems, either to be promoted as an alternative or a complement to other crops which are poorly adapted to erratic or irregular rainfall and increased temperatures.

APPENDIX TABLES

APPENDIX TABLE A.1.

SUMMARISED ADAPTIVE CAPACITY (AC) INDICATORS COLLECTED FOR ALL PROVINCES OF RWANDA [21]

Indicator category	Adaptive capacity indicators	Eastern	Kigali	Northern	Southern	Western
Adoption of improved agricultural practices	% of plots using organic fertilisers	35.2	45.9	64.7	60.5	55.7
	% of plots using pesticides	6.7	4.7	12.4	9.4	15.9
	% use of improved seeds	6.1	4.1	6.8	5.6	7.8
Access to agricultural information	% households that own a radio	73.1	91.5	73.2	67.2	69.5
	% households that have received extension services	26.9	9.3	33.6	31.4	31.6
Education	% Literacy rate at age 10	69.4	86.6	71.4	68.8	68.0
Education	Employment rate	85.4	82.4	90.3	85.9	85.9

[21] Derived from Agricultural Household Survey, http://statistics.gov.rw/publication/agricultural-household-survey-2017; and Labour Force Survey Report, http://statistics.gov.rw/publication/labour-force-survey-report-december-2018

APPENDIX TABLE A.2.

PROJECTED INFLUENCE OF CLIMATE CHANGE ON MEAN MONTHLY TEMPERATURE (°C) IN THE PROVINCES OF RWANDA AT HISTORICAL AND MID-CENTURY PERIODS, AND MONTHLY ANOMALIES BETWEEN THE TWO TIME PERIODS

		MONTH											
		J	F	M	A	M	J	J	A	S	O	N	D
NORTHERN	Historical (°C)	19.4	19.8	19.6	19.3	19.1	18.9	19.2	20.0	20.0	19.7	19.2	19.2
	Future (°C)	21.2	21.6	21.4	21.1	21.0	21.0	21.3	22.2	22.1	21.6	20.9	21.0
	Anomaly (°C)	1.8	1.8	1.8	1.8	1.9	2.1	2.1	2.2	2.1	1.9	1.7	1.8
SOUTHERN	Historical (°C)	19.9	20.2	20.1	19.8	19.7	19.6	19.9	20.9	21.0	20.6	19.8	19.9
	Future (°C)	21.7	22.1	21.9	21.6	21.7	21.7	22.0	23.0	23.1	22.5	21.5	21.7
	Anomaly (°C)	1.8	1.9	1.8	1.8	1.9	2.1	2.1	2.1	2.1	2.0	1.7	1.8
EASTERN	Historical (°C)	20.8	21.1	20.9	20.5	20.5	20.5	20.9	21.8	21.7	21.2	20.4	20.6
	Future (°C)	22.6	23.0	22.7	22.3	22.4	22.6	23.0	23.9	23.8	23.2	22.2	22.4
	Anomaly (°C)	1.8	1.9	1.8	1.8	1.9	2.1	2.1	2.1	2.1	2.0	1.7	1.8
WESTERN	Historical (°C)	19.1	19.5	19.4	19.3	19.1	18.9	19.0	19.8	20.0	19.7	19.1	19.1
	Future (°C)	21.0	21.4	21.3	21.1	21.1	21.0	21.2	22.0	22.1	21.6	20.8	20.9
	Anomaly (°C)	1.9	1.9	1.8	1.8	2.0	2.1	2.2	2.1	2.1	2.0	1.7	1.8
KIGALI	Historical (°C)	20.5	20.9	20.6	20.2	20.0	20.0	20.4	21.4	21.4	20.9	20.1	20.3
	Future (°C)	22.4	22.8	22.5	22.0	21.9	22.1	22.5	23.5	23.5	22.9	21.8	22.1
	Anomaly (°C)	1.8	1.8	1.8	1.8	1.9	2.1	2.1	2.1	2.1	2.0	1.7	1.8

APPENDIX TABLE A.3.

PROJECTED INFLUENCE OF CLIMATE CHANGE ON MEAN MONTHLY PRECIPITATION (MM/MONTH) IN THE PROVINCES OF RWANDA AT HISTORICAL AND MID-CENTURY PERIODS, AND MONTHLY ANOMALIES BETWEEN THE TWO TIME PERIODS

mm/month		MONTH												
		J	F	M	A	M	J	J	A	S	O	N	D	Total
NORTHERN	Historical	92	102	136	155	118	29	19	48	106	137	149	100	**1191**
	Future	97	100	129	143	93	23	18	43	95	123	150	104	**1115**
	Anomaly	+5	-3	-6	-12	-25	-6	-2	-5	-12	-15	+0	+4	**-75**
SOUTHERN	Historical	118	116	150	172	121	22	13	34	85	131	159	118	**1240**
	Future	120	115	144	161	96	17	11	28	74	115	156	122	**1158**
	Anomaly	+2	-1	-7	-11	-26	-5	-2	-6	-11	-16	-3	+4	**-82**
EASTERN	Historical	83	86	121	149	100	16	12	31	74	107	136	91	**1004**
	Future	85	87	117	138	78	12	10	27	64	95	135	94	**941**
	Anomaly	+3	+1	-5	-11	-21	-4	-2	-4	-10	-13	-1	+4	**-63**
WESTERN	Historical	121	117	150	156	121	34	20	44	101	144	161	128	**1295**
	Future	120	113	142	146	97	26	18	37	92	129	159	131	**1210**
	Anomaly	-1	-4	-8	-10	-25	-7	-2	-6	-9	-15	-2	+3	**-86**
KIGALI	Historical	87	99	130	154	109	19	13	33	81	117	138	91	**1072**
	Future	91	99	125	143	86	14	11	29	70	104	138	95	**1005**
	Anomaly	+4	0	-5	-11	-23	-5	-2	-4	-11	-14	0	+4	**-67**