

Future Climate Scenarios for Uganda's Tea Growing Areas

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1 Authors and contact details

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2 Executive summary

This document reports on the methods and results of a consultancy with the title “Future Climate Scenarios for Uganda’s Tea Growing Areas” conducted for the Cafédirect Producers’ Foundation.

The methodology applied was based on the combination of current climate data with future climate change predictions from 20 models for 2020 and 2050. The data of the current climate and the climate change was used as input to Maxent, a crop prediction model. The evidence data (coordinates) used for Maxent were collected by Global Positioning Systems (GPS) through field work in Uganda. Due to lack of coordinates from Hoima district near Lake Albert, results may not be reliable for this area.

The analysis focused on the specific municipalities that were of interest to the client and provide predictions of the future climate and predictions of the suitability of current tea-growing areas to continue growing tea by 2020 and 2050. The results show that the change in suitability under progressive climate change is site-specific. There will be districts that become unsuitable for tea by 2050 such as Kyejojo, Bundibugyo, Bushenyi, Kanungu, Masaka, where farmers will need to identify alternative crops. There will be districts that remain suitable for tea such as Kabarole, Kisoro, but only when the farmers adapt their agronomic management to the new conditions the area will experience. There will be areas where suitability of tea increases (some slight areas around Rwenzori National Park and the southwestern corner of Uganda). However many of these latter areas are usually protected areas and it is not recommended to clear forest or invade protected areas in order to produce tea. The serious loss of suitability of tea to future climate predictions implies a high importance of crop diversification for tea farmer in Uganda.

In Uganda the yearly and monthly rainfall will increase and the yearly and monthly minimum and maximum temperatures will increase moderately by 2020 and progressively increase by 2050. The overall climate will become less seasonal in terms of variation through the year in temperature with temperature in specific districts increasing by about 1 °C by 2020 and 2.3 °C by 2050 and more seasonal in precipitation with the maximum number of cumulative dry month staying constant at 3 months. The implications are that the distribution of suitability’s within the current tea-growing areas in Uganda for

tea production in general will decrease quite seriously by 2050. The suitable areas will migrate up the altitudinal gradient which rarely exists in Uganda. Areas that retain some suitability will see decreases of between 20% - 40%, compared with today's suitability of 60% - 80%.

The optimum tea-producing zone is currently at an altitude between 1450 - 1650 meters above sea level (masl) and will, by 2050, increase to an altitude between 1550 - 1650 masl. By 2050 areas at altitudes between 1500 - 1650 masl will suffer the highest decrease in suitability. Increasing altitude will compensate for the increase in temperature. Unfortunately, however, the fact that there is not much land available in higher altitudes leads to the conclusion that total land area available for cultivation will ultimately decrease.

A comparison of potential diversification crops evaluated by the project show that by 2050, the current tea growing area would only be suitable for 1 of the 6 alternative crops being considered, and as such would not be an ideal option. For 2020, however, some of them, especially maize, passion fruit, banana or citrus could be an option to losing climate-suitability for tea. We have concluded that more diversification options have to be investigated following this study.

3 Project Background and Objectives

The objectives of this study is to develop future climate scenarios indicating the adaptability/suitability of tea under changing climatic conditions for Uganda's tea growing zones, and indicating potentials for alternative crops suitable under predicted climate change.

Currently the tea growing areas in Uganda are in the following districts: Lake Victoria Crescent in the districts of Mukono, Mubende, Mityana, Masaka and Wakiso and the lower slopes of Rwenzori Mountains in Kabarole district and above the Western Rift Valley in the districts of Bushenyi, Kyenjojo, Kibaale, Hoima and Kanungu.



Figure 1: Study zone and Uganda's tea growing areas

4 Key objectives

To predict the change in climate for tea growing areas in Uganda

To predict the impact of progressive climate change on tea suitability in Uganda

To predict the impact of progressive climatic change on the most important diversification crops

5 Methodology

5.a Current climate

As current climate (baseline) we used historical climate data from www.worldclim.org database (Hijmans *et al.*, 2005). The WorldClim data are generated through interpolation of average monthly climate data from weather stations on a 30 arc-second resolution grid (often referred to as "1 km" resolution). Variables included are monthly total precipitation, and monthly mean, minimum and maximum temperature, and 19 bioclimatic variables (Hijmans *et al.*, 2005a).

In the WorldClim database, climate layers were interpolated using:

- Major climate databases compiled by the Global Historical Climatology Network (GHCN), the FAO, the WMO, the International Center for Tropical Agriculture (CIAT), R-HYdronet, and a number of additional minor databases for Australia, New Zealand, the Nordic European Countries, Ecuador, Peru, Bolivia, amongst others.
- The SRTM elevation database (aggregated to 30 arc-seconds, "1 km")
- The ANUSPLIN software. ANUSPLIN is a program for interpolating noisy multi-variate data using thin plate smoothing splines. We used latitude, longitude, and elevation as independent variables.

For stations for which there were records for multiple years, the averages were calculated for the 1960-90 period. Only records for which there were at least 10 years of data were used. In some cases the time period was extended to the 1950-2000 period to include records from areas for which there were few recent records available (e.g., DR Congo) or predominantly recent records (e.g., Amazonia).

After removing stations with errors, the database consisted of precipitation records from 47,554 locations, mean temperature from 24,542 locations, and minimum and maximum temperature for 14,835 locations.

The data on which WorldClim is based in Uganda are from 371 stations with precipitation data, 351 stations with mean temperature, and 28 stations with minimum and maximum temperatures.

Bioclimatic variables

Within the WorldClim database, there are bioclimatic variables that were derived from the monthly temperature and rainfall values to generate more biologically meaningful variables, which are often used in ecological niche modeling (e.g., BIOCLIM, GARP). The bioclimatic variables represent annual trends (e.g., mean annual temperature, annual precipitation) seasonality (e.g., annual range in temperature and precipitation) and extreme or limiting environmental factors (e.g., temperature of the coldest and warmest month, and precipitation of the wettest and driest quarters). A quarter is a period of three months (1/4 of the year).

The derived bioclimatic variables are:

Bio1 = Annual Mean Temperature

Bio2 = Mean Diurnal Range (Mean of monthly (max temp - min temp))

Bio3 = Isothermality (Bio2/Bio7) (* 100)

Bio4 = Temperature Seasonality (standard deviation *100)

Bio5 = Maximum Temperature of Warmest Month

Bio6 = Minimum Temperature of Coldest Month

Bio7 = Temperature Annual Range (Bio5 – Bio6)

Bio8 = Mean Temperature of Wettest Quarter

Bio9 = Mean Temperature of Driest Quarter

Bio10 = Mean Temperature of Warmest Quarter

Bio11 = Mean Temperature of Coldest Quarter

Bio12 = Annual Precipitation
Bio13 = Precipitation of Wettest Month
Bio14 = Precipitation of Driest Month
Bio15 = Precipitation Seasonality (Coefficient of Variation)
Bio16 = Precipitation of Wettest Quarter
Bio17 = Precipitation of Driest Quarter
Bio18 = Precipitation of Warmest Quarter
Bio19 = Precipitation of Coldest Quarter

5.b Future climate

Global circulation models

A global circulation model (GCM) is a computer-based model that calculates and predicts how climate patterns will be in a number of years in the future. GCMs use equations of motion as a numerical weather prediction (NWP) model, with the purpose of numerically simulating changes in the climate as a result of slow changes in some boundary conditions (such as the solar constant) or physical parameters (such as the concentration of greenhouse gases). The model focuses on each grid cell and the transfer of energy between grid cells. Once the simulation is calculated a number of climate patterns can be determined; from ocean and wind currents to patterns in precipitation and rates of evaporation that affect, for example, lake-levels and growth of agricultural plants. The GCMs are run in a number of specialized computer laboratories around the world. We used data in our analyses from these laboratories.

Generation of predictions for future climate

The Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report was based on the results of 21 global climate models (GCMs), data for which are available through an IPCC interface, or directly from the institutions that developed each individual model. The spatial resolution of the GCM results is inappropriate for analyzing the impacts on agriculture as in almost all cases the grid cells measure more than 100 km a side. This is especially a problem in heterogeneous landscapes such as those of the Andes, where, in some places, one cell can cover the entire width of the range.

Downscaling is therefore needed to provide higher-resolution surfaces of expected future climates if the likely impacts of climate change on agriculture are to be more accurately forecast.

We used a simple downscaling method (named delta method), based on the sum of interpolated anomalies to high-resolution monthly climate surfaces from WorldClim (Hijmans *et al.*, 2005a). The method, basically, produces a smoothed (interpolated) surface of changes in climates (deltas or anomalies) and then applies this interpolated surface to the baseline climate (from WorldClim), taking into account the possible bias due to the difference in baselines. The method assumes that changes in climates are only relevant at coarse scales, and that relationships between variables are maintained towards the future (Ramirez and Jarvis, 2010).

CIAT downloaded the data from the Earth System Grid (ESG) data portal and applied the downscaling method on over 19 GCMs from the IPCC Fourth Assessment Report (2007) for the emission scenario SRES-A2 and for 2 different 30 year running mean periods (i.e. 2010-2039 [2020s], 2040-2069 [2050s]).

Each dataset (SRES scenario – GCM – time slice) comprises 4 variables at a monthly time-step (mean, maximum, minimum temperature, and total precipitation), on a spatial resolution of 30 arc-seconds (Ramirez and Jarvis, 2010).

5.c Crop prediction

Maximum Entropy

Maximum entropy (MAXENT) is a general-purpose method for making predictions or inferences from incomplete information. The idea is to estimate a target probability distribution by finding the probability distribution of maximum entropy, subject to a set of constraints that represent (one's) incomplete information about the target distribution. The information available about the target distribution often presents itself as a set of real-valued variables, called 'features', and the constraints are that the expected value of each feature should match its empirical average -"average value for a set of sample points taken from the target distribution"(Phillips *et al.*, 2006 pg234). Similar to logistic regression, MAXENT weights each environmental variable by a constant. The probability distribution is the sum of each weighed variable divided by a scaling constant to ensure that the probability value ranges from 0 to 1. The program starts with a uniform probability distribution and iteratively alters one weight at a time to maximize the likelihood of reaching the optimum probability distribution. MAXENT is generally considered to be the most accurate model (Elith *et al.*, 2006).

Ecocrop

For most of the crops that are not staples or commodity crops there is a lack of detailed information. Hijmans *et al.*, (2005b) have developed a mechanistic model based on the Ecocrop database (FAO, 1998 available at <http://ecocrop.fao.org/ecocrop/srv/en/home>) to spatially predict crop suitability without having prior knowledge or data available. The model essentially uses minimum, maximum, and mean monthly temperatures, and total monthly rainfall to determine a suitability index based on each parameter separately (i.e. temperature, rainfall), to finally determine an overall suitability rating (from 0 to 100) by multiplying both temperature and rainfall indices. Ecocrop does not require any coordinates or ground data and is therefore rather generic. To improve the results we use existing knowledge of geographic crop distribution such as the Spatial Production Allocation Model (SPAM), the Global Biodiversity Information Facility (GBIF), CIAT own databases and expert knowledge gathered on the ground. With a minimum of 60-100 geo-referenced sample sites gathered across the different sources we re-calculated the environmental factor ranges to improve the model. GPS-coordinates of the Ugandan tea growing sample sites are supplied by the project partners.

5.d Measure of confidence

Future crop suitability is predicted using each of the GCM models via Ecocrop algorithms described above. Two measurements of uncertainty are computed: (1) the agreement among models calculated as percentage of models predicting changes in the same direction as the average of all models at a given location and (2) the coefficient of variation (CV) among models. After initial runs, models that are significantly different from those of the other models according to Tukey's (1977) outlier test will be removed from further analysis.

5.e Environmental factors driving change in suitability

In order to understand the relative importance of different climatic drivers, we then carried out a forward, step-wise regression analysis with the suitability shift per data point as the dependent variable and the model-average changes in the bioclimatic variables between the present and future as the independent variables, and calculating the relative contribution of each variable to the total predicted suitability shift in terms of the proportion of R-square explained when adding each variable to the linear regression model. This analysis was carried out separately for the data points showing positive and negative shifts in suitability.

6 Result I: Climate change summary of tea production sites

6.a The summary climate characteristics for all tea factory sites in Uganda

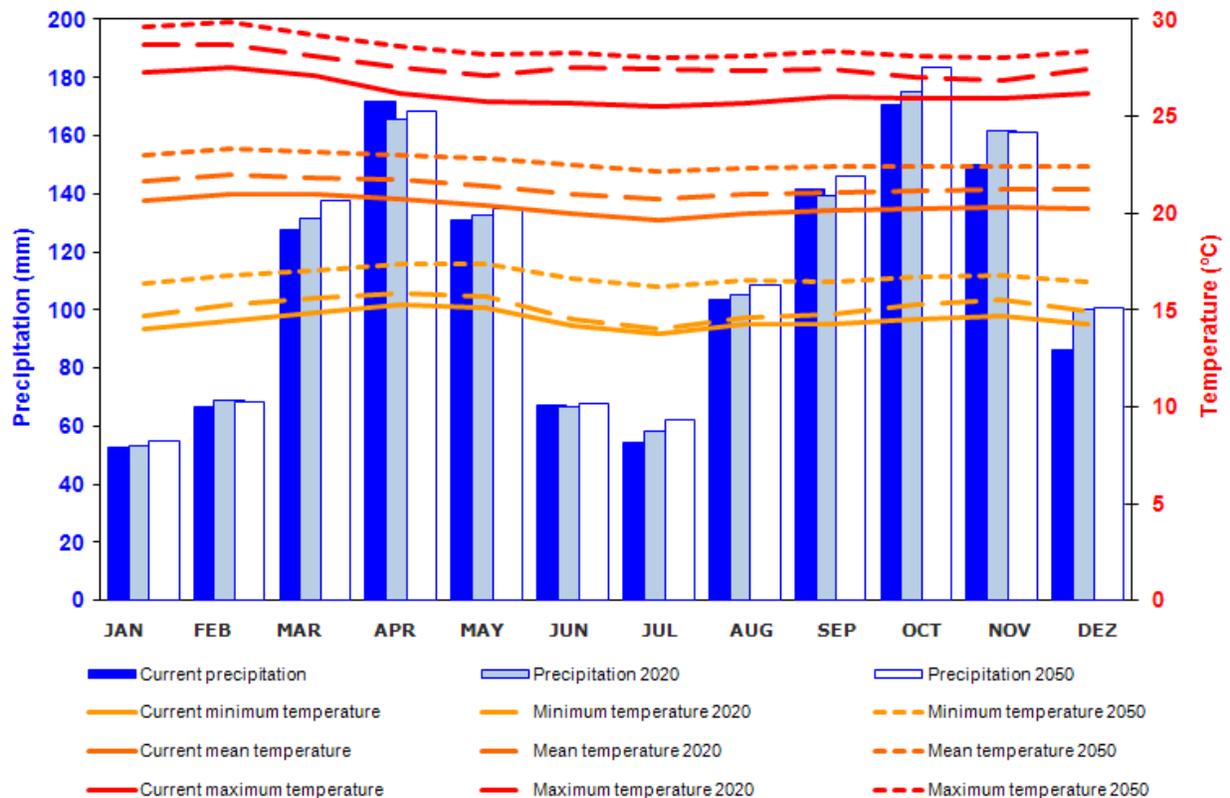


Figure 2: Climate trend summary 2020 and 2050 for sample sites

General climatic characteristics

- Rainfall increases from 1324 millimeters to 1394 millimeters in 2050 passing through 1358 in 2020
- Temperatures increase and the average increase is 2.3 °C passing through an increment of 1.0 °C in 2020
- The mean daily temperature range keeps constant on 11.8 °C in 2050
- The maximum number of cumulative dry months keeps constant in 3 months

Extreme conditions

- The maximum temperature of the year increases from 27.5 °C to 30.1 °C while the warmest quarter gets hotter by 2.4 °C in 2050
- The minimum temperature of the year increases from 13.6 °C to 15.8 °C while the coldest quarter gets hotter by 2.3 °C in 2050
- The wettest month gets wetter with 202 millimeters instead of 188 millimeters, while the wettest quarter gets wetter by 28 mm in 2050
- The driest month stays constant with around 43 millimeters while the driest quarter gets wetter by 12 mm in 2050

Climate Seasonality

- Overall this climate becomes less seasonal in terms of variability through the year in temperature and less seasonal in precipitation

Variability between models

- The coefficient of variation of temperature predictions between models is 3%
- Temperature predictions were uniform between models and thus no outliers were detected
- The coefficient of variation of precipitation predictions between models is 11%
- Precipitation predictions were uniform between models and thus no outliers were detected

6.b Regional changes in the mean annual precipitation (2020)

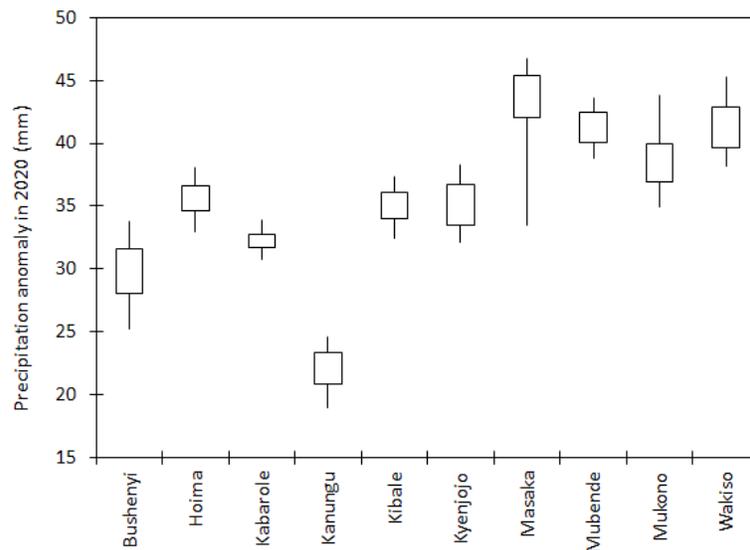


Figure 3: Mean annual precipitation change by 2020 for 10 tea-growing districts of Uganda.

The edges of the boxes indicate the mean maximum and mean minimum values and the ends of the line the maximum and minimum values. The mean maximum and mean minimum values are defined by the mean + or – the standard deviation.

The mean annual precipitation increases in 2020 on average by 34 mm and in 2050 by 70 mm. In 2020 the districts Masaka, Wakiso, Mubende and Mukono will have larger increase in precipitation than the

others (Figure 3) and in 2050 Masaka will have the largest increase (Figure 4). We observed the smallest increase in precipitation for 2020 in Kanungu and in 2050 in Kabarole, Kibale and Kanungu.

6.c Regional changes in the mean annual precipitation (2050)

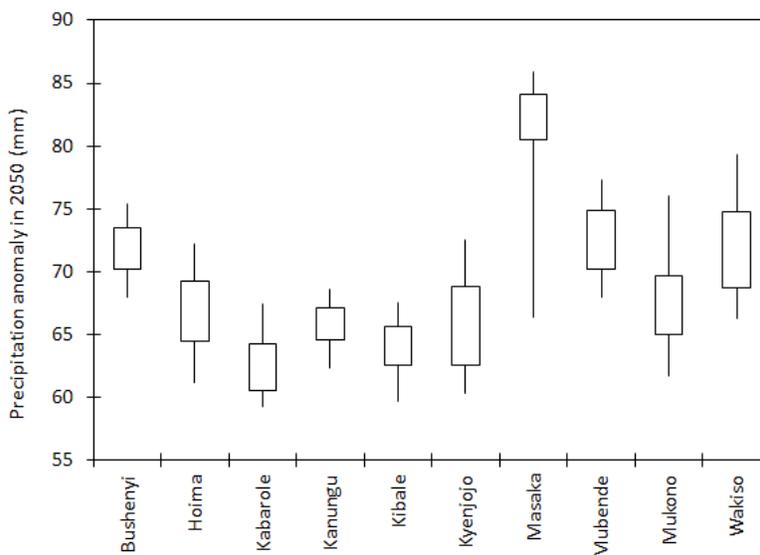


Figure 4: Mean annual precipitation change by 2050 for 10 tea-growing districts of Uganda.

The edges of the boxes indicate the mean maximum and mean minimum values and the ends of the line the maximum and minimum values. The mean maximum and mean minimum values are defined by the mean + or – the standard deviation.

6.d Regional changes in the mean annual temperature (2020)

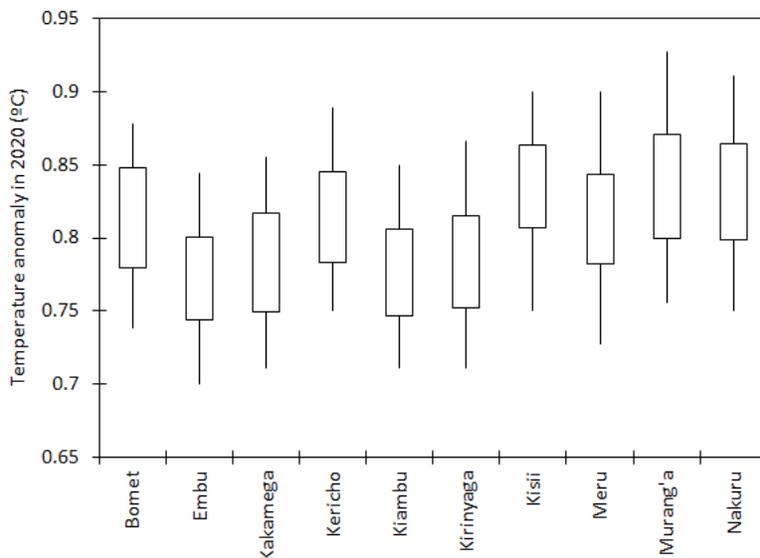


Figure 5: Mean annual temperature change by 2020 for 10 tea-growing districts of Uganda.

The edges of the boxes indicate the mean maximum and mean minimum values and the ends of the line the maximum and minimum values. The mean maximum and mean minimum values are defined by the mean + or – the standard deviation.

The mean annual temperature will increase progressively. The increase by 2050 is between 2.1 and 2.3 °C (Figures 6) and for 2020 between 0.7 and 0.9 °C (Figures 5).

6.e Regional changes in the mean annual temperature (2050)

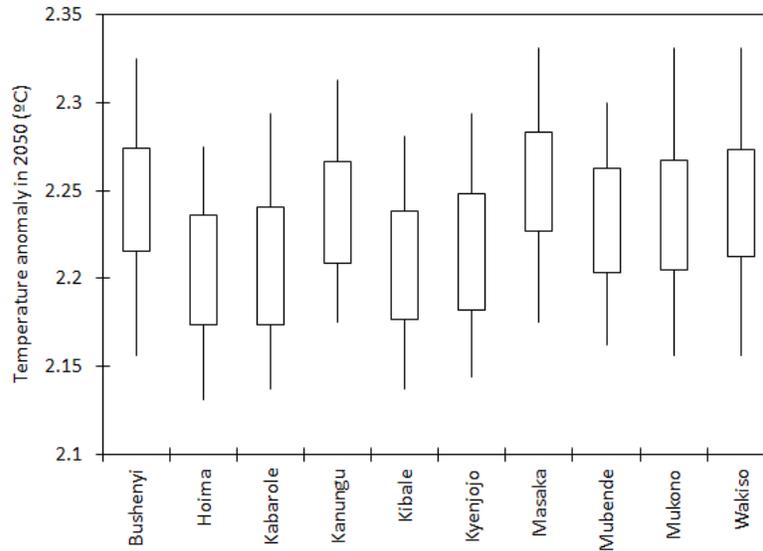


Figure 6: Mean annual temperature change by 2050 for 10 tea-growing districts of Uganda.

The edges of the boxes indicate the mean maximum and mean minimum values and the ends of the line the maximum and minimum values. The mean maximum and mean minimum values are defined by the mean + or – the standard deviation.

7 Result II: Suitability maps of tea production areas

7.a Current suitability of tea production areas

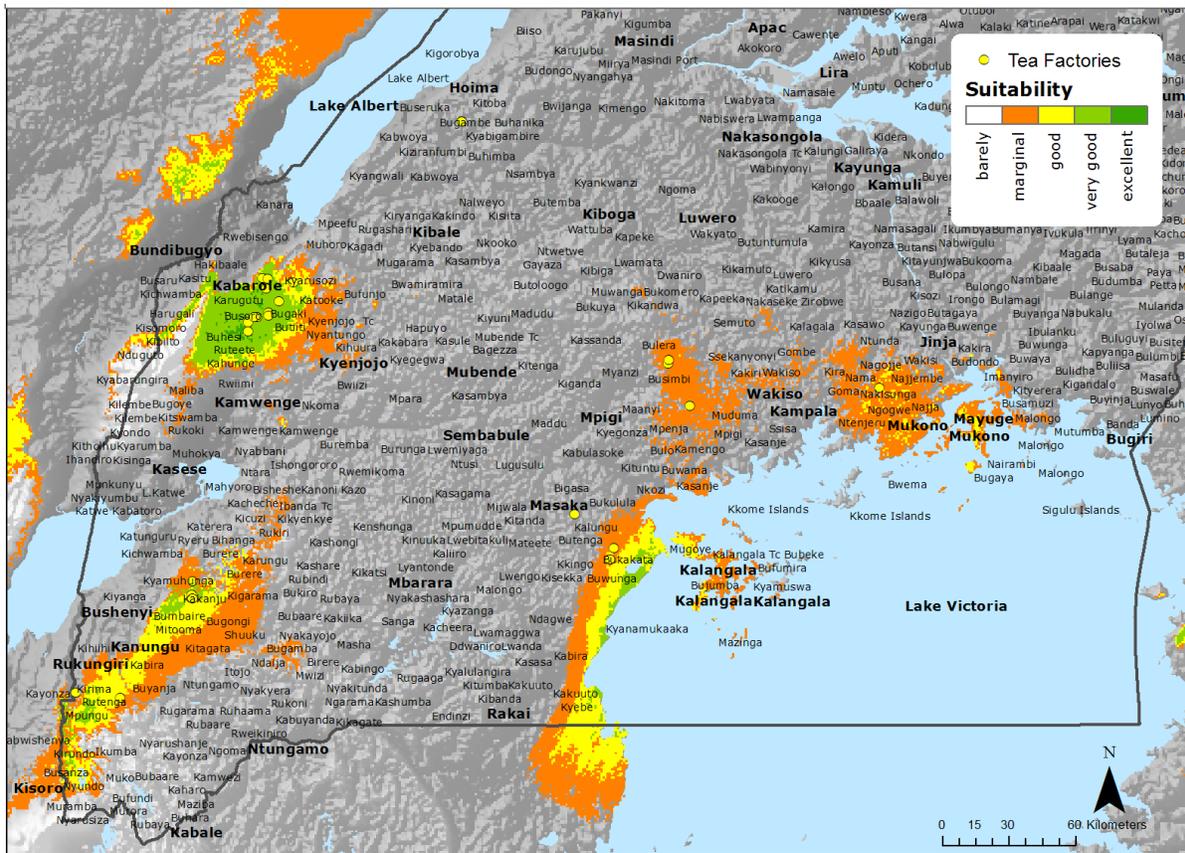


Figure 7: Current suitability for tea production within tea-growing districts of Uganda.

Currently, the main tea-producing areas with high climate-suitability in Uganda are located above the Western Riff Valley, western lakeside and south of Lake George (Figure 7). According to the MAXENT model, the most suitable of them are concentrated in the higher areas of districts: Kabarole, Kyejojo, Bundibugyo, Bushenyi, Kanungu, Kisaro and Masaka. The remaining districts are in general rather less suitable. According to ‘expert knowledge’, there are some areas in Hoima district that are currently tea growing areas but seem to be not climate-suitable based on our analysis. The reason is because of missing evidence data in the region (Hoima district is represented by 1 point) and the fact, that this is the lowest region (around 1000 masl) of the study area on altitude and it seems to be the lower limit in terms of altitude for tea in the study area.

Find more detailed maps of current and future tea suitability in focal regions in Annex I to II.

7.b Future suitability of tea production areas

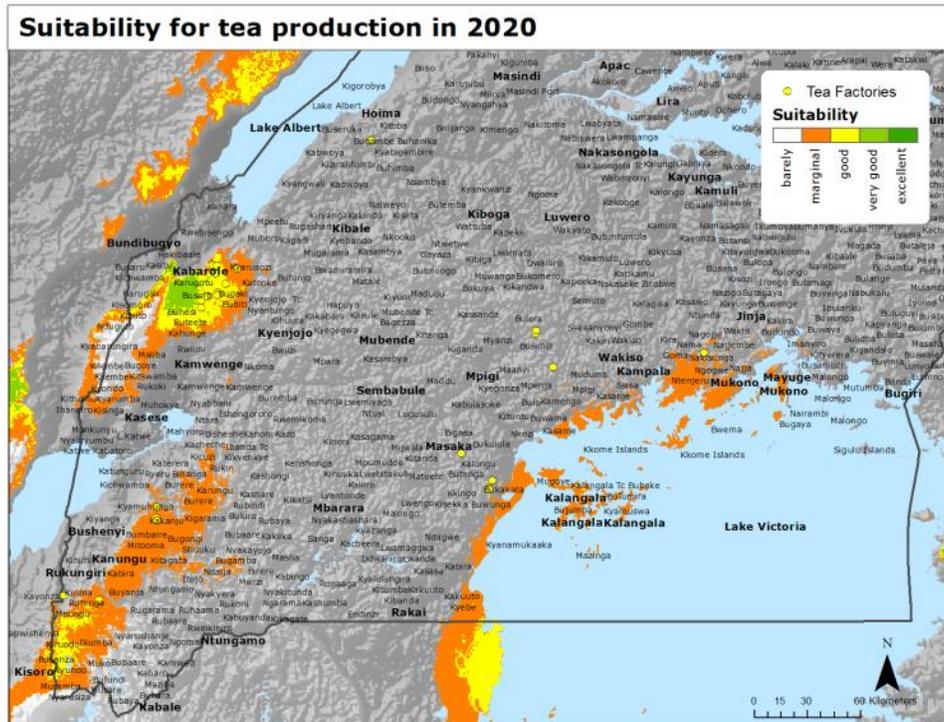


Figure 8: Suitability for tea production in 2020.

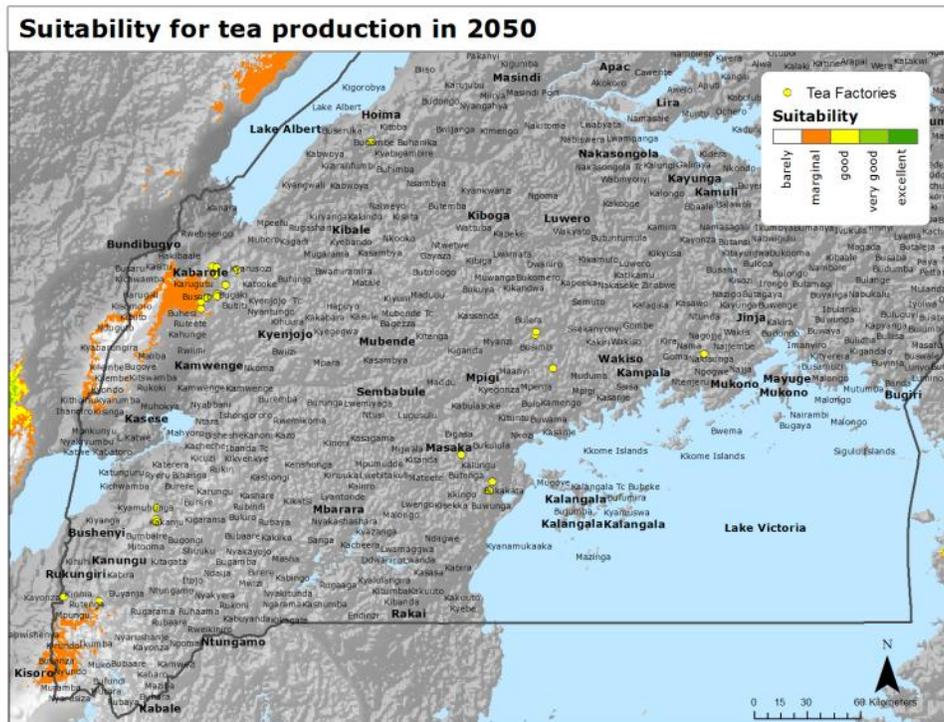


Figure 9: Suitability for tea production in 2050.

In 2020 suitable areas start decreasing quite serious in most of Uganda's current tea growing areas. (Figure 8). We assume that some areas will still be suitable enough to grow tea under climate conditions similar to today, at least in Kabarole and Kisoro. In 2050 tea production according to its climate-suitability is predicted to disappear almost completely (Figure 9). The western region in general is anticipated to have a higher suitability level. The coefficient of variation (CV) for 2020 and 2050 bioclimatic variables ranges between 0 and 15%, and may therefore be accepted as reliable (Figure 10).

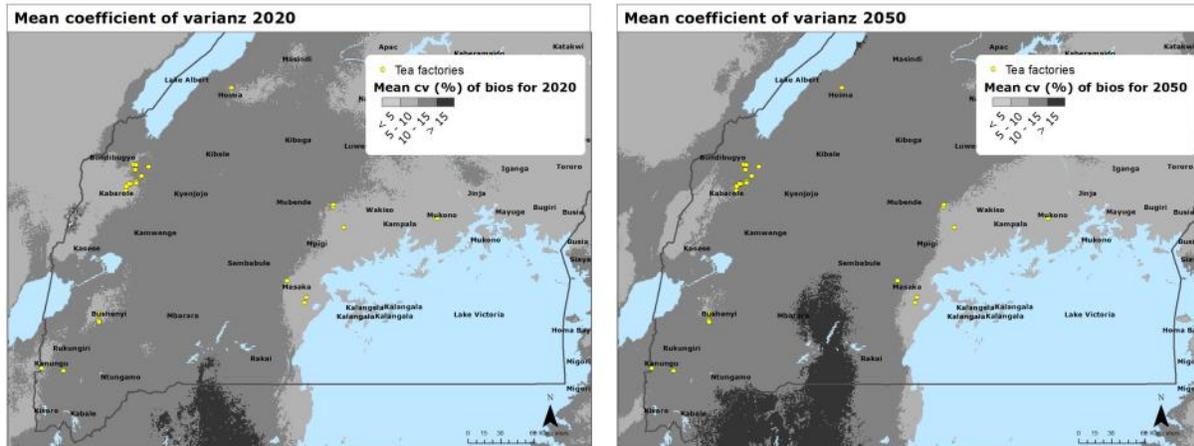


Figure 10: Mean coefficient of variance of bioclimatic variables in 2020 and 2050.

7.c Suitability change of tea production areas

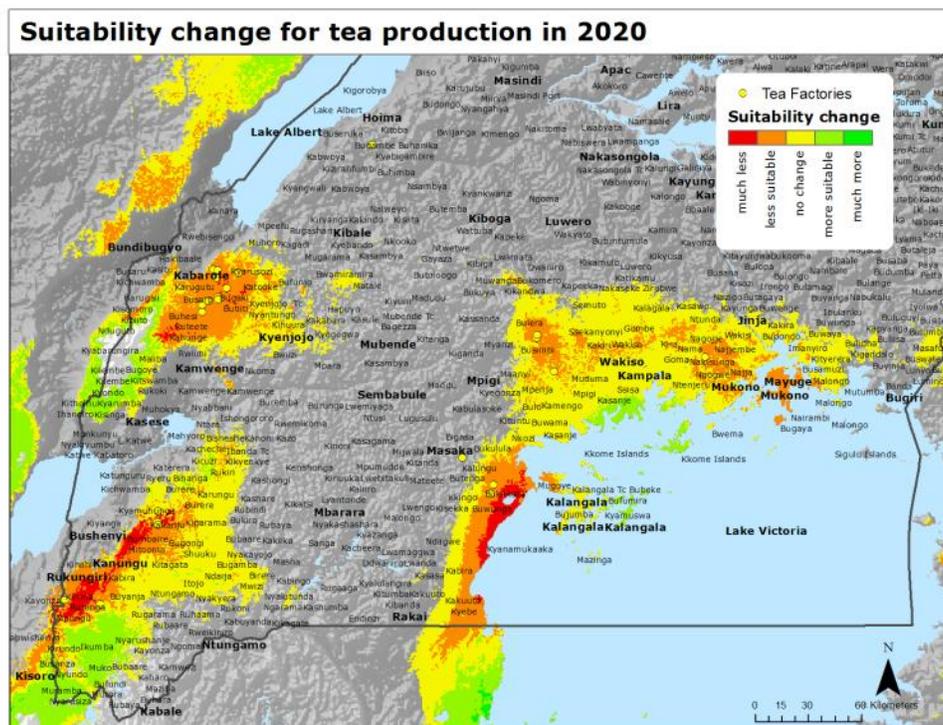


Figure 11: Suitability change for tea production in 2020.

While in the western area of Rwenzori National Park and the southwestern corner of Uganda around Lake Mutanda the climate-suitability of tea shows a slight increase by 2020, the rest of Uganda's tea growing areas are losing suitability (Figure 11). In 2050 tea-growing areas decreases quite seriously in all current tea growing areas (Figure 12). The average suitability areas in Kabarole decrease to between 20 and 40%, whereas today they have suitability of more than 60 and up to 80%. Areas in the southwest still remain suitable to climate in 2050. While there is a general shift to higher altitudes, those gaining areas around Rwenzori National Park increase suitability around 10 to 30%. The most significant loss of suitability (up to -60%) can be observed in Kabarole district. The Measure of agreement of models predicting changes in the same direction as the average of all models at a given location is between 70% - 100% in tea growing areas (Figure 13).

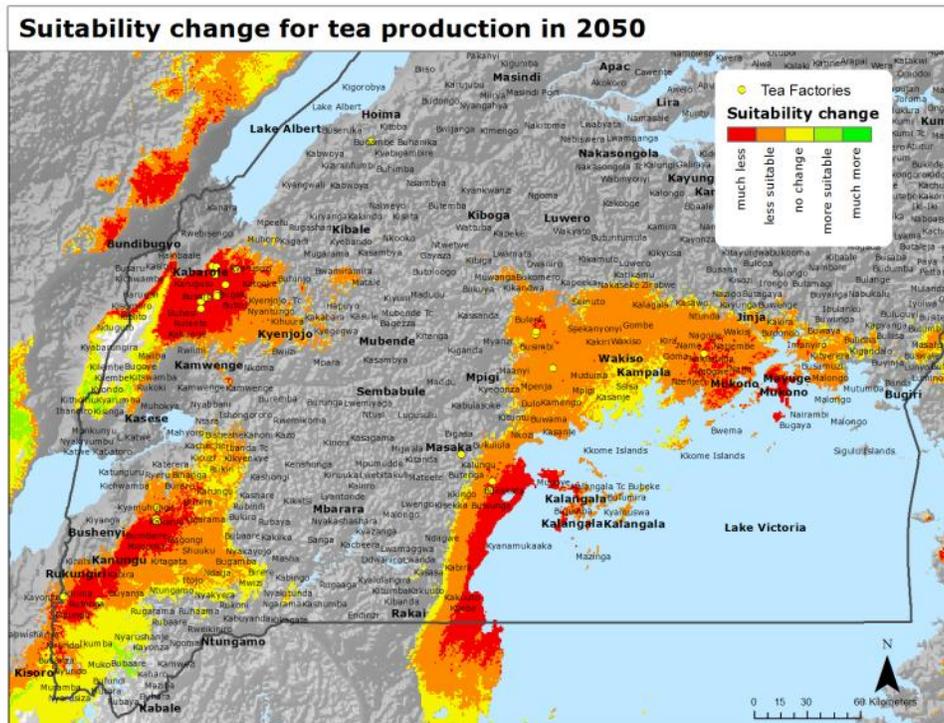


Figure 12: Suitability change for tea production in 2050.

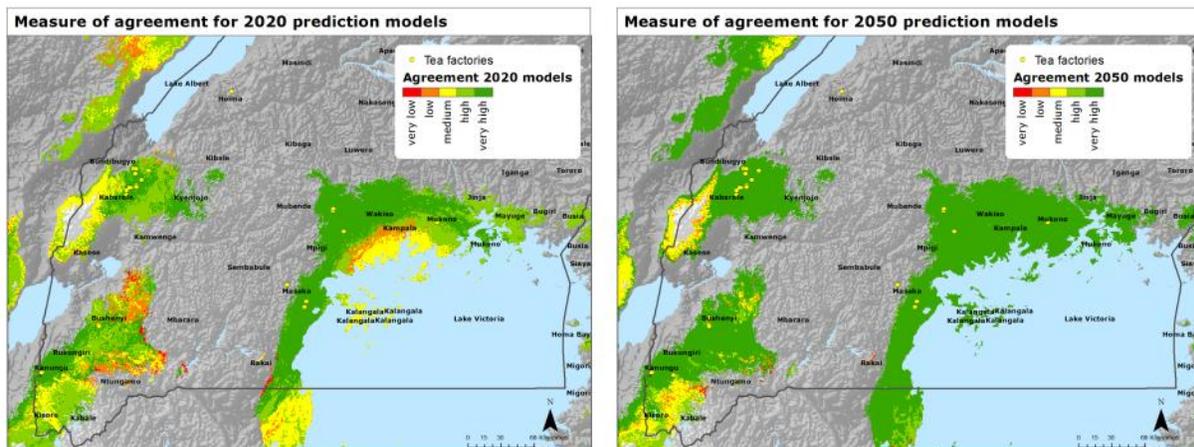


Figure 13: Measure of agreement of models predicting changes in the same direction as the average of all models at a given location for 2020 and 2050.

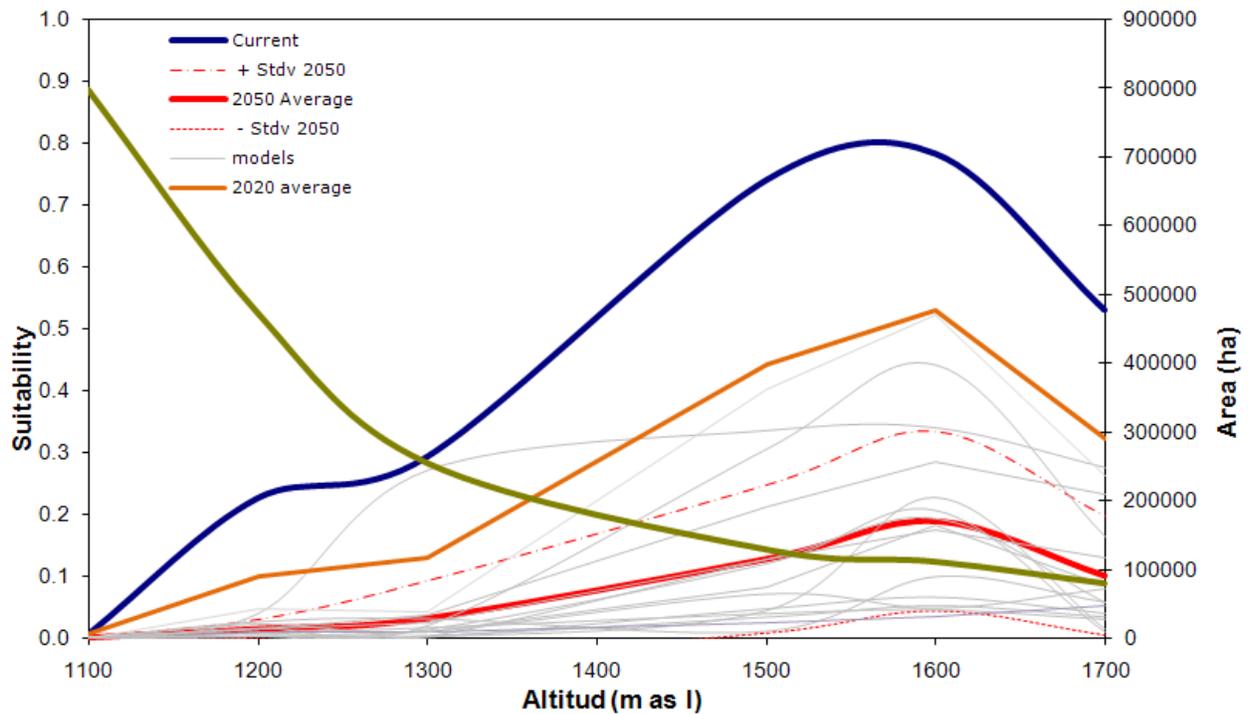


Figure 14: The relation between the suitability of areas for tea production and altitude for current climates, and predicted for 2020 and 2050 in Uganda.

With progressive climate change, areas at higher altitudes benefit on tea-suitability (Figure 14). Altitude was not used in the suitability modeling and is therefore independent of the other variables. Altitude is however very much correlated with temperature-related variables. The optimum tea-producing zone is currently at an altitude between 1450 - 1650 masl and by 2050, will increase to an altitude between 1550 - 1650 masl. Compared with today, by 2050 areas at altitudes between 1500 - 1650 masl will suffer the highest decrease in suitability. (Figure 14).

8 Result III: Environmental factors which drive the suitability of tea

The regression analysis identifies primarily the bioclimatic variables related to precipitation increase and general increasing temperature as drivers of the predicted suitability shifts.

The increases of precipitation and min temperature during the cold season together with Isothermality (quantification of how large the day-to-night temperature oscillation is in comparison to the summer-to-winter oscillation) explain 97.5% of decreasing suitability for 2020.

The 45% of observed locations with increasing suitability for 2020 are influenced by increasing precipitation during the wet season and a general annual precipitation increase (Table 1).

Table 1: Contribution of different bioclimatic variables to the predicted shift in suitability for tea in Uganda, between the present and the 2020s, separating locations with decreasing and increasing suitability^a

Variable	Adjusted R2	R2 due to variable	% of total variability	Present mean	Change by 2020s
Locations with decreasing suitability (n=61, 55 % of all observations)					
BIO 19 – Precipitation of coldest quarter	0.6176	0.6176	76.4	295 mm	+ 31 mm
BIO 03 – Isothermality	0.7314	0.1138	14.1	85	- 2
BIO 06 – Min temperature of coldest month	0.7876	0.0562	7.0	10.0 °C	+ 1.0 °C
others	-	-	2.5		
Locations with constant or increasing suitability (n=50, 45 % of all observations)					
BIO 16 – Precipitation of wettest quarter	0.2897	0.1298	31.1	706 mm	+ 12 mm
BIO 12 – Annual precipitation	0.1042	0.1042	25.0	1620 mm	+ 41 mm
BIO 01 – Annual mean temperature	0.1577	0.0535	12.8	16.9 °C	+ 0.8 °C
BIO 17 – Precipitation of driest quarter	0.3759	0.0519	12.4	192 mm	+ 5 mm
BIO 19 – Precipitation of coldest quarter	0.4170	0.0411	9.9	263 mm	+ 1 mm
BIO 08 – Mean temperature of wettest quarter	0.3240	0.0343	8.2	17.4 °C	+ 0.7 °C
others	-	-	0.6		

^aVariables explaining less than 4% of total variability are not listed.

The regression analysis for changes in suitability on observed sample points for 2050 describes temperature seasonality as main driving factor for negative suitability change (Table 2). Increasing precipitations explain 89.9% of positive suitability change for 22.5% of observed points.

Table 2: Contribution of different bioclimatic variables to the predicted shift in suitability for tea in Uganda, between the present and the 2050s, separating locations with decreasing and increasing suitability^a

Variable	Adjusted R2	R2 due to variable	% of total variability	Present mean	Change by 2050s
Locations with decreasing suitability (n=86, 77.5% of all observations)					
BIO 04 – Temperature seasonality	0.3308	0.3308	55.1	680	- 20
BIO 16 – Precipitation of wettest quarter	0.3804	0.0496	8.3	605 mm	+ 24 mm
BIO 18 – Precipitation of warmest quarter	0.5497	0.0360	6.0	374 mm	+ 35 mm
BIO 03 – Isothermality	0.4153	0.0349	5.8	84.6	- 1.5
BIO 19 – Precipitation of coldest quarter	0.4726	0.0292	4.9	307 mm	+ 47 mm
BIO 09 – Mean temperature of driest quarter	0.4434	0.0281	4.7	18.7 °C	+ 2.1 °C
BIO 13 – Precipitation of wettest month	0.5003	0.0277	4.6	253 mm	+ 7 mm
others	-	-	10.6		
Locations with constant or increasing suitability (n=25, 22.5% of all observations)					
BIO 18 – Precipitation of warmest quarter	0.5459	0.5459	66.6	542 mm	+ 7 mm
BIO 12 – Annual precipitation	0.8194	0.1909	23.3	1635 mm	+ 69 mm
BIO 01 – Annual mean temperature	0.6285	0.0485	5.9	15.9 °C	+ 2.1°C
BIO 03 – Isothermality	0.5800	0.0341	4.2	79	- 1.2
others	-	-	0		

^aVariables explaining less than 4% of total variability are not listed.

9 Result IV: Indications of adaptation strategies

9.a Identification of potential diversification strategies

To address potential diversification strategies for tea farms affected by progressive climate change on their tea production we identified six crops:

- Maize
- Cassava
- Pineapple
- Banana
- Passion fruit
- Citrus

Because a lack of detailed data (GPS coordinates) suitability of alternative crops were calculated using a mechanistic model based on the Ecocrop database. We improved the model by using existing knowledge of geographic crop distribution and calibrated the input-values on a regional scale.

9.b Suitability of potential diversification crops

Suitability of Maize

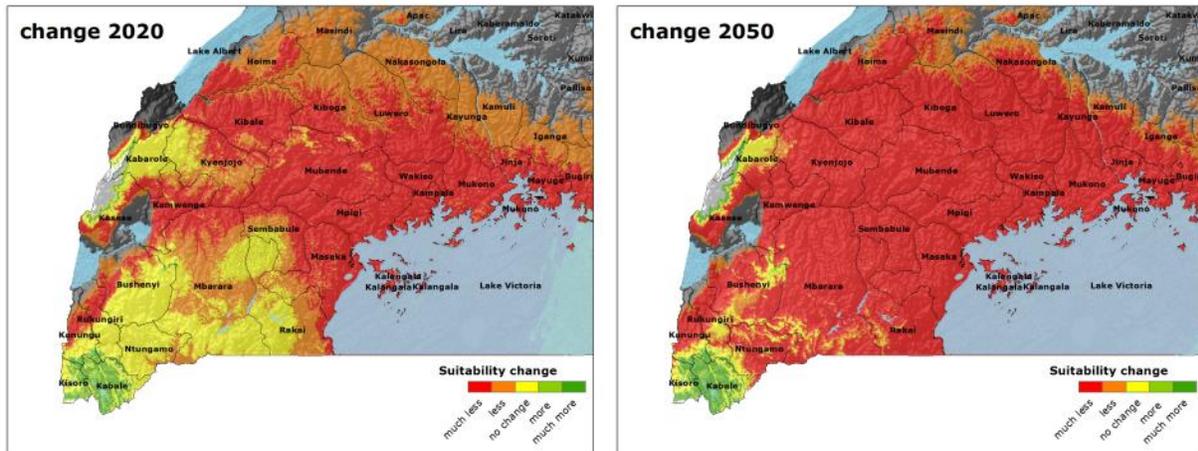


Figure 15: Suitability change of maize.

While suitability of banana (Figure 17), pineapple (Figure 18) and citrus (Figure 20) remains constant until 2020, maize losing in 2020 some and for 2050 most of its suitable areas (Figure 15). Cassava performs quite well on suitability change (Figure 16) in the region and some increase in suitability is predicted. Banana will increase its area of suitability right up until 2050 (Figure 18), while passion fruit will decrease its suitability quite seriously but will have some increases in areas in the south west (Figure 19).

Suitability of Cassava

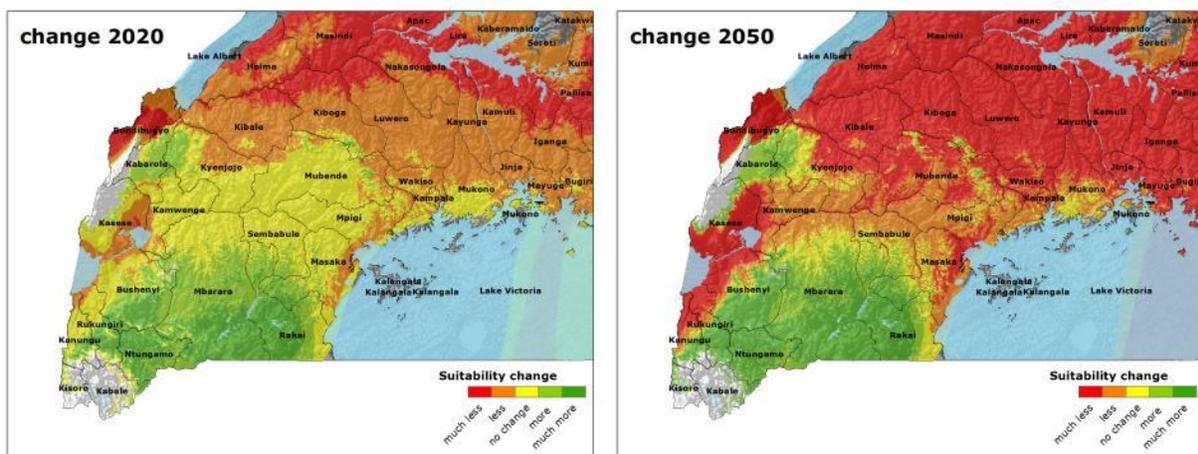


Figure 16: Suitability change of cassava.

Suitability of Pineapple

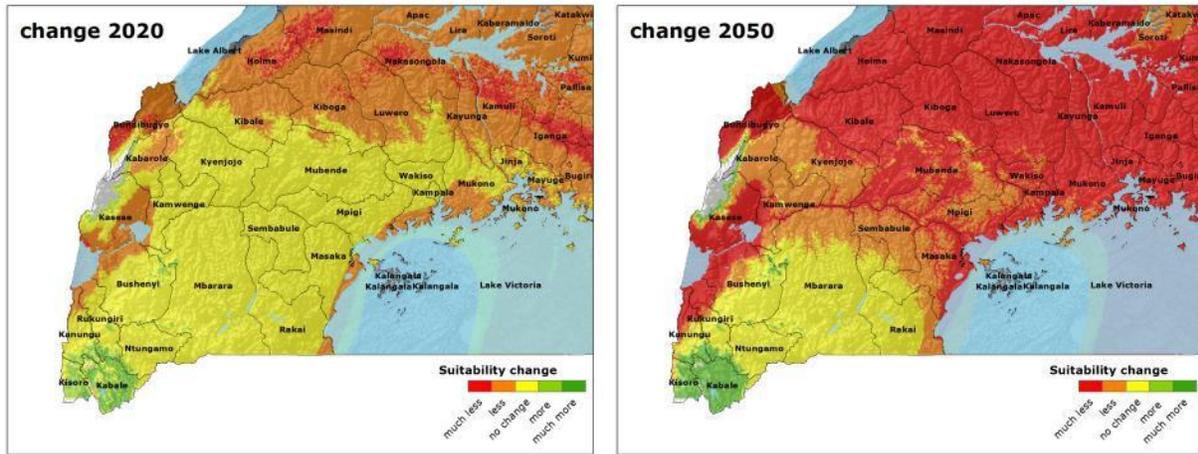


Figure 17: Suitability change of pineapple.

Suitability of Banana

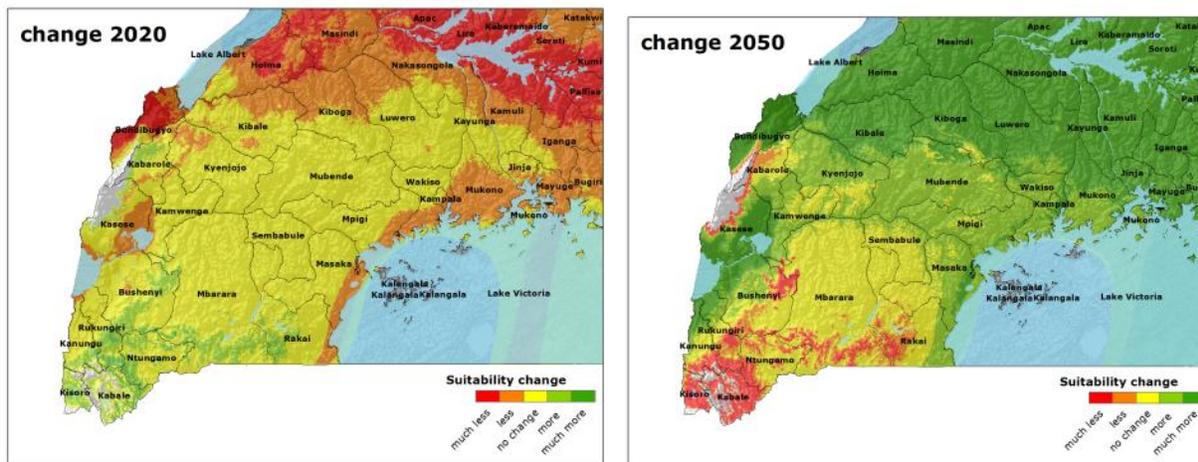


Figure 18: Suitability change of banana.

Suitability of Passion fruit

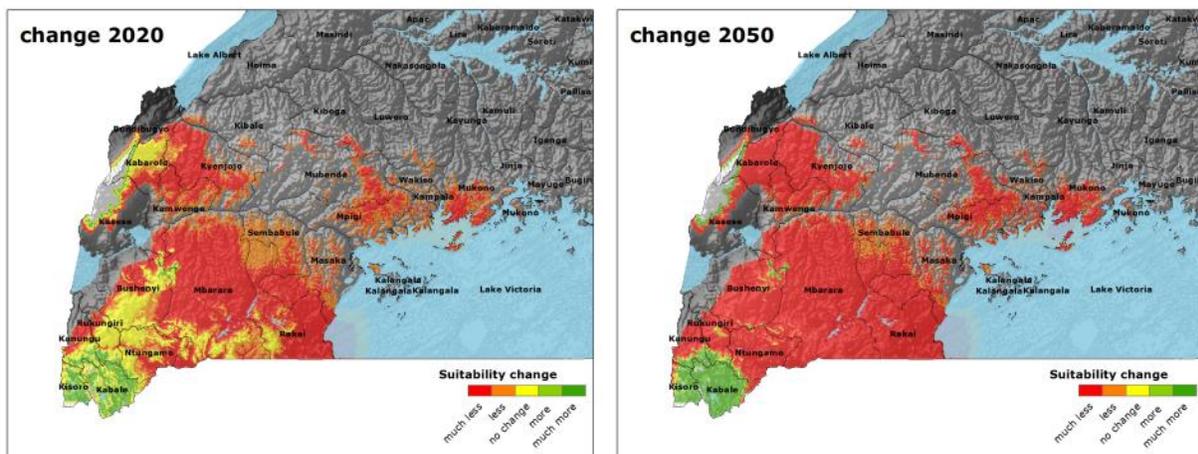


Figure 19: Suitability change of passion fruit.

Suitability of Citrus

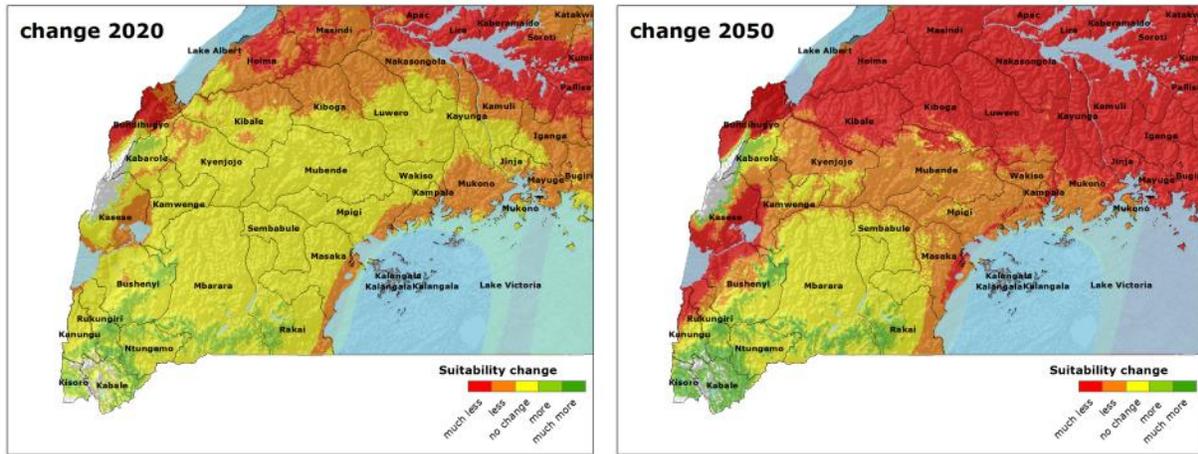


Figure 20: Suitability change of citrus

Table 3: Comparison of suitability change of tea and diversification crops on 26 tea growing factories in Uganda

2020	Tea	Banana	Cassava	Citrus	Maize	Passion fruit	Pineapple
<i>suitability change</i>							
much less	70	-	-	-	-	-	-
less suitable	15	6	11	6	6	11	6
no change	15	25	-	25	67	-	25
more suitable	-	-	-	-	-	-	-
much more	-	-	-	-	-	-	-

2050	Tea	Banana	Cassava	Citrus	Maize	Passion fruit	Pineapple
<i>suitability change</i>							
much less	65	-	-	-	-	-	-
less suitable	23	-	-	-	-	-	-
no change	12	-	-	-	-	-	-
more suitable	-	-	-	-	-	-	-
much more	-	-	-	-	-	-	-

Table 3 compares suitability change for tea growing factories and their potential for diversification into other crops. As illustrated in the table, for 2050 almost none of the examined alternative crops had climatically suitable areas in tea growing areas, thus, these crops would not be good alternatives. For 2020 some of them, especially maize, passion fruit, banana or citrus could be an alternative crop for tea.

10 Conclusions

- In Uganda the yearly and monthly rainfall will increase and the yearly and monthly minimum and maximum temperatures will increase by 2020 and progressively increase by 2050.
- The implications are that the distribution of suitability within the current tea-growing areas in Uganda for tea production in general will decrease quite seriously by 2050.
- The optimum tea-producing zone is currently at an altitude between 1450 and 1650 masl and will by 2050 increase to an altitude between 1550 and 1650 masl.
- Compared with today, by 2050 areas at altitudes between 1500 and 1650 masl will suffer the highest decrease in suitability and no areas will increase in suitability.
- A comparison of potential diversification crops recommended by the project show that for 2050 almost none of the examined alternative crops will have their suitable areas in tea growing areas, thus other the suitability of other alternative crops will need to be explored. For 2020 some of them, especially maize, passion fruit, banana or citrus could be an option to losing climate-suitability for tea.

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Annex II: Suitability maps of Mpanga Growers Tea Factory Limited and Mabaale Growers Tea Factory

