Future Climate Scenarios for Kenya's Tea Growing Zones

Pic by Neil Palmer (CIAT)

CIAT International Center for Tropical Agriculture

- **CIAT:** Part of Consultative Group on International Agriculture Research
- **Mission:** To reduce hunger and poverty, and improve human health in the tropics through research aimed at increasing the eco-efficiency of agriculture.

What we do: Site-Specific-Management, Impact monitoring, Market research, Ecosystem services (DAPA), climate change (CCAFS), Plant breeding (CIAT), …

Project-Team:
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Project background

A

Study zone and Kenya's tea growing areas

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

ETP and GIZ aim to increase Kenyan tea producers' resilience to climate change to secure their future livelihoods and make these livelihoods more environmentally and economically sustainable. In order to achieve this, the two partners have formed a 3-year Public Private Partnership which will train approximately 10,000 vulnerable Kenyan farmers on the most appropriate adaptation techniques

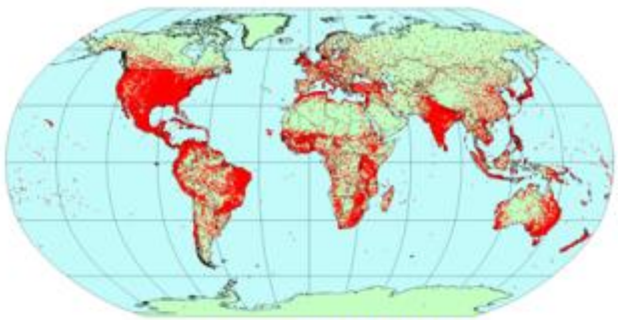
Research questions

B

- Where will tea grow in the future?
- Where will tea not grow any more?
- Where can tea still grow with adapted mgt?
- What are the decisive factors to manage?

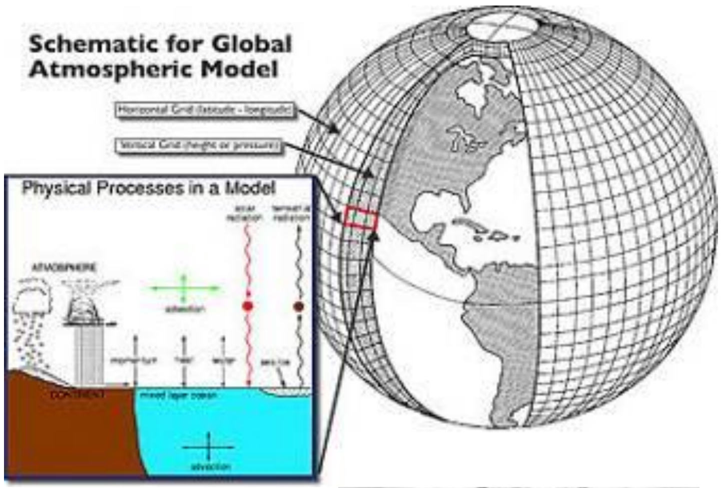
Pics by Neil Palmer (CIAT)

Methodology

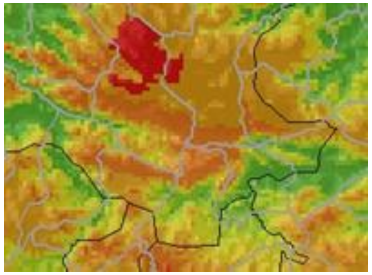


WorldClim (www.worldclim.org)
(Hijmans et al, 2005)

Current climate from historical climate generation



Global circulation models as future climate



Suitability prediction

Current climate

WorldClim (www.worldclim.org) database
(Hijmans et al, 2005)

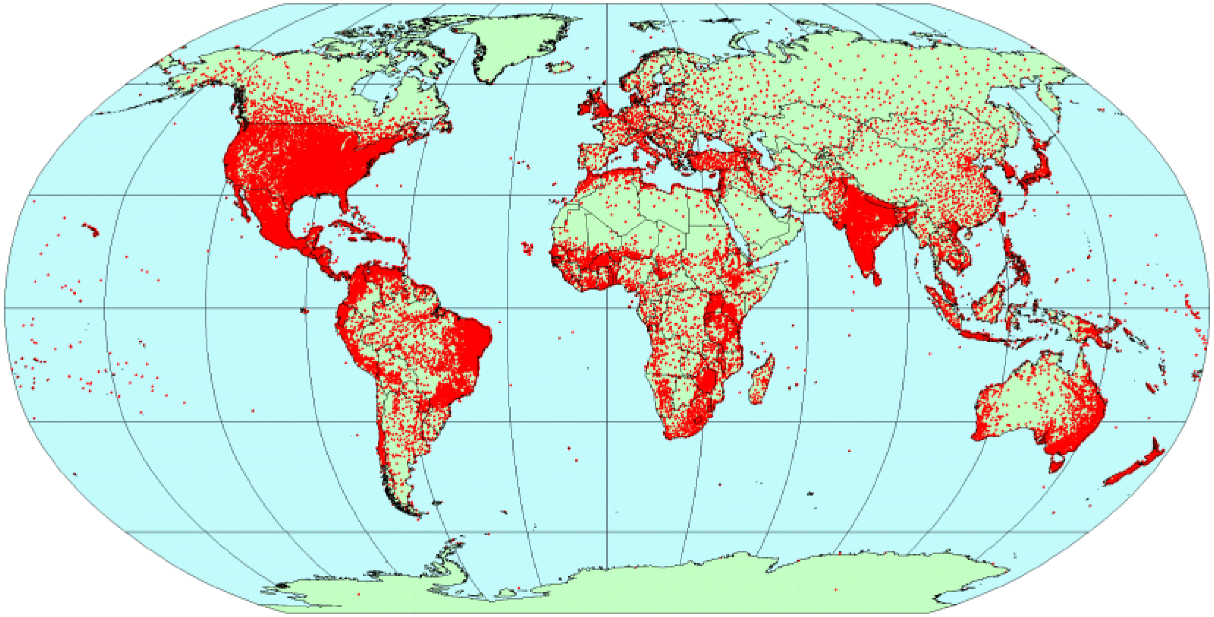
- Base line for climate change calculations
- Meteorological Stations with data of:

- Worldwide:

precipitation: 47,554
Mean temp.: 24,542
Min/max temp: 14,835

- For Kenya:

Precipitation: 736
Mean temp.: 708
Min/max temp: 61



Current climate: Bioclimatic variables

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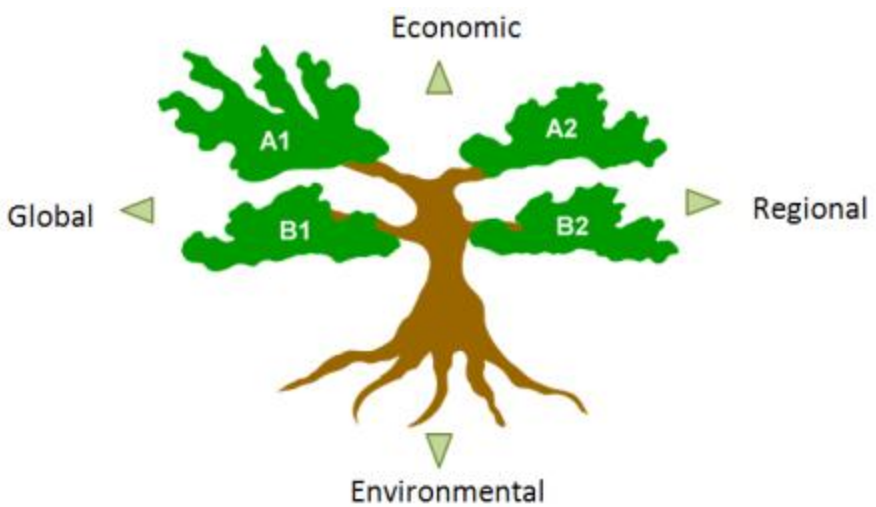
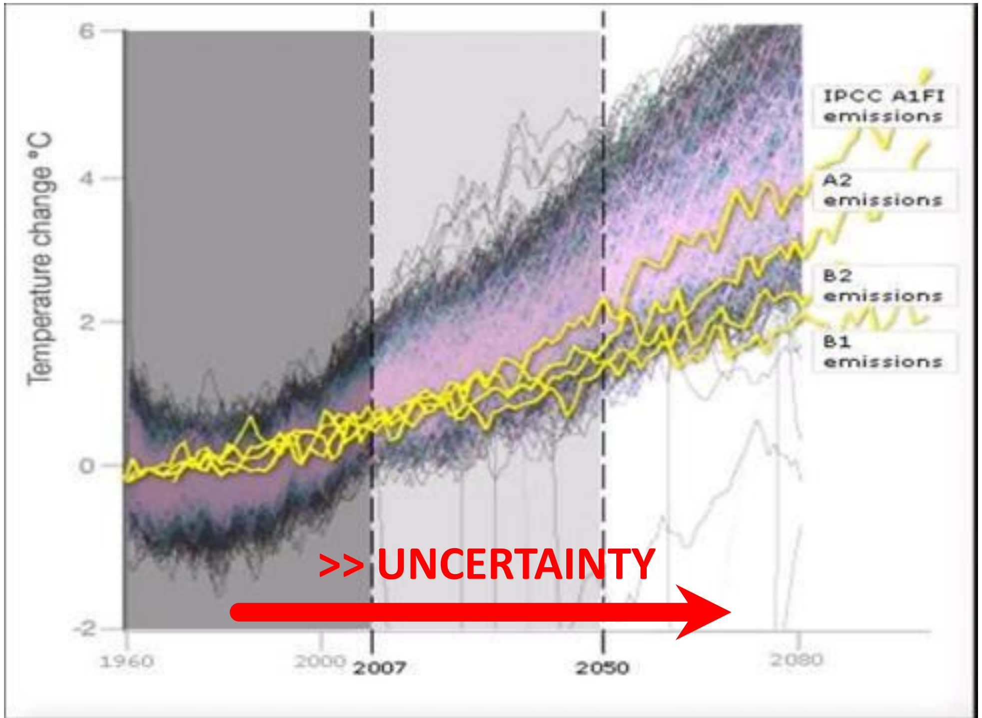
- Bio1 = Annual mean temperature
- Bio2 = Mean diurnal range (Mean of monthly (max temp - min temp))
- Bio3 = Isothermality (Bio2/Bio7) (* 100)
- Bio4 = Temperature seasonality (standard deviation *100)
- Bio5 = Maximum temperature of warmest month
- Bio6 = Minimum temperature of coldest month
- Bio7 = Temperature Annual Range (Bio5 – Bi06)
- 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

- **Global circulation models** (GCM)

Calibrated in the past (using time-series) and projected to the future





Emission scenarios = Political uncertainty
Global Circulation Models = Scientific uncertainty

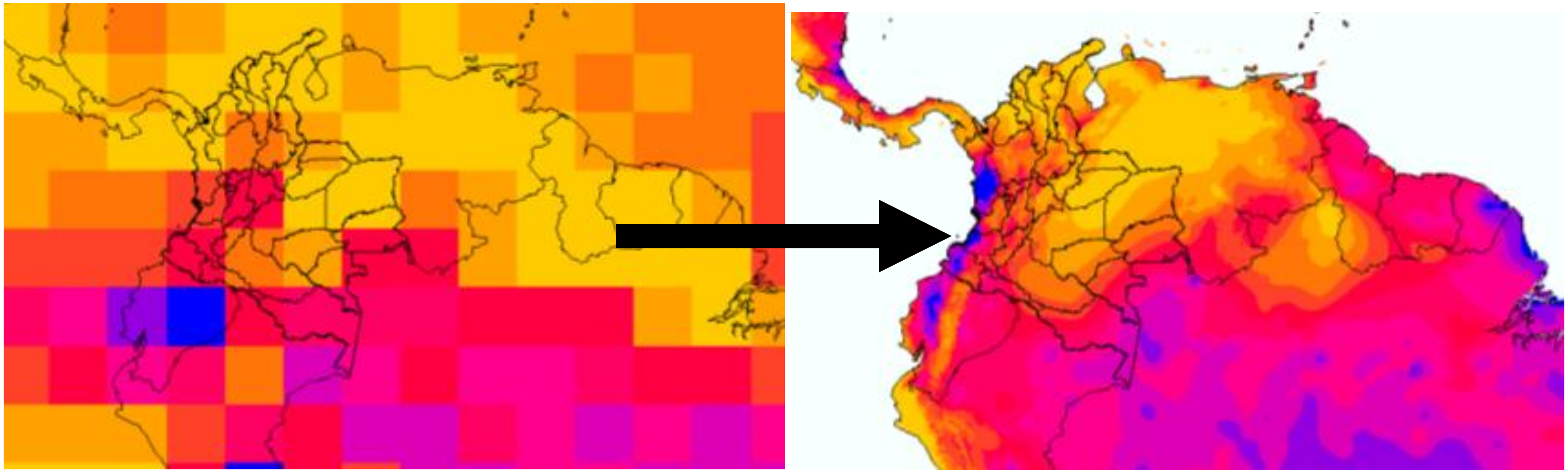
- **Intergovernmental Panel on Climate Change** - IPCC (http://www.ipcc.ch/)

Fourth Assessment Report, based on the results of 21 global climate models (GCMs)

Future climate: Global circulation models (GCM)

Model	Country	Atmosphere	Ocean
BCCR-BCM2.0	Norway	T63, L31	1.5x0.5, L35
CCCMA-CGCM3.1 (T47)	Canada	T47 (3.75x3.75), L31	1.85x1.85, L29
CCCMA-CGCM3.1 (T63)	Canada	T63 (2.8x2.8), L31	1.4x0.94, L29
CNRM-CM3	France	T63 (2.8x2.8), L45	1.875x(0.5-2), L31
CSIRO-Mk3.0	Australia	T63, L18	1.875x0.84, L31
CSIRO-Mk3.5	Australia	T63, L18	1.875x0.84, L31
GFDL-CM2.0	USA	2.5x2.0, L24	1.0x(1/3-1), L50
GFDL-CM2.1	USA	2.5x2.0, L24	1.0x(1/3-1), L50
GISS-AOM	USA	4x3, L12	4x3, L16
GISS-MODEL-EH	USA	5x4, L20	5x4, L13
GISS-MODEL-ER	USA	5x4, L20	5x4, L13
IAP-FGOALS1.0-G	China	2.8x2.8, L26	1x1, L16
INGV-ECHAM4	Italy	T42, L19	2x(0.5-2), L31
INM-CM3.0	Russia	5x4, L21	2.5x2, L33
IPSL-CM4	France	2.5x3.75, L19	2x(1-2), L30
MIROC3.2-HIRES	Japan	T106, L56	0.28x0.19, L47
MIROC3.2-MEDRES	Japan	T42, L20	1.4x(0.5-1.4), L43
MIUB-ECHO-G	Germany/Korea	T30, L19	T42, L20
MPI-ECHAM5	Germany	T63, L32	1x1, L41
MRI-CGCM2.3.2A	Japan	T42, L30	2.5x(0.5-2.0)
NCAR-CCSM3.0	USA	T85L26, 1.4x1.4	1x(0.27-1), L40
NCAR-PCM1	USA	T42 (2.8x2.8), L18	1x(0.27-1), L40
UKMO-HADCM3	UK	3.75x2.5, L19	1.25x1.25, L20
UKMO-HADGEM1	UK	1.875x1.25, L38	1.25x1.25, L20

- Delta (Hay et al. 2007)
  - Base climate: **WORLDCLIM,** Used in most studies of CC.
  - Take original GCM surfaces (time series)
  - Calculate averages for baseline & specific periods
  - Calculate anomalies
  - Interpolate anomalies
  - Add anomalies to **WORLDCLIM**



Suitability prediction: tea

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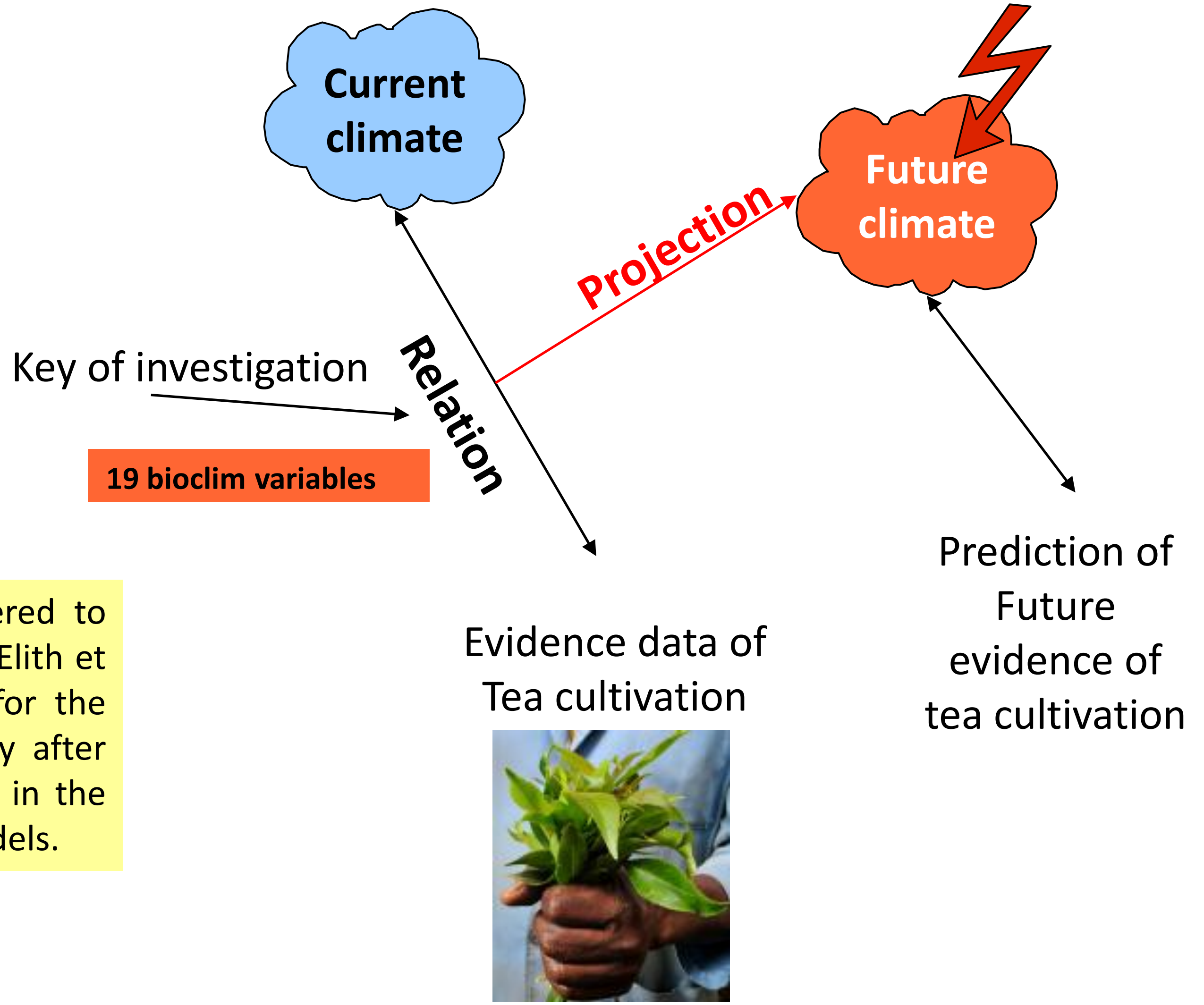
- Finding the probability distribution of maximum entropy (**MAXENT**)



MAXENT is generally considered to be the most accurate model (Elith et al. 2006) and was selected for the analyses of the present study after an initial iteration of analysis in the study region using all four models.

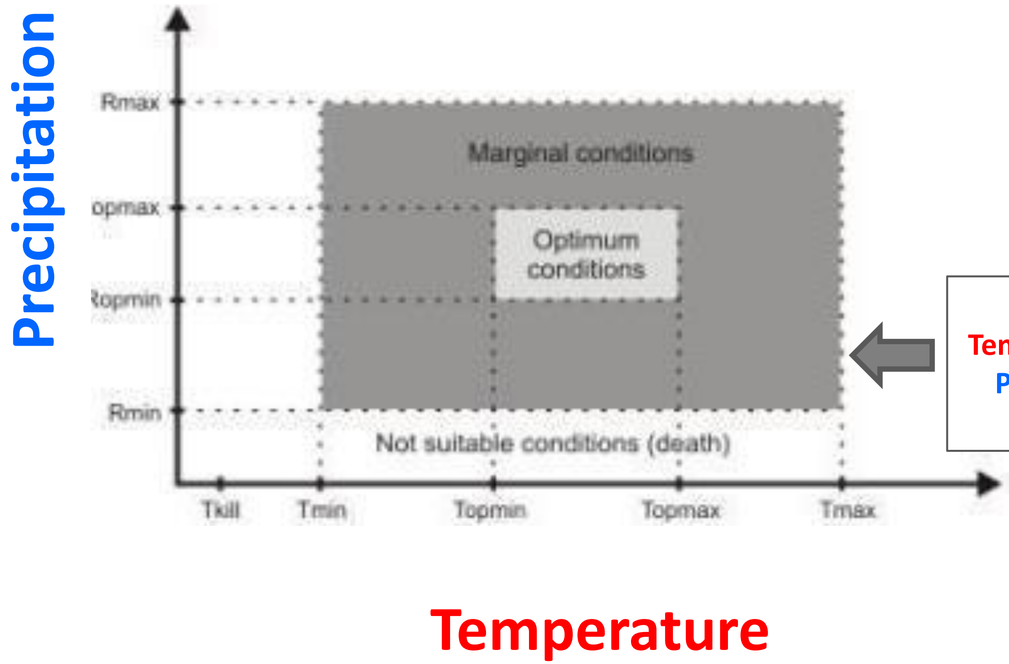
- A mechanistic model to spatially predict crop suitability (**ECOCROP**)

Current Suitability

Future Suitability 2050

Change in Suitability to Future Climate (2050)

more suitable
no change
less suitable



Calibrated Temperature and Precipitación Ranges!

Ecocrop Database (FAO)

(Food and Agriculture Organization of the UN)

Ranges: Temperature and precipitation

Calibration with optimal points

- Samples (GPS points)
- Altitude range
- Current Production Areas
- Soil types

WorldClim Climate Data

http://worldclim.org

More than 47,000 stations worldwide

The process

- Compilation of evidence data (by partner)
- Generation of future climates
- MaxEnt / Ecocrop:
  Future suitability predictions for each model
  - 3 measurements of uncertainty to exclude outliers:
    - agreement among models as percentage of models predicting changes in the same direction
    - mean suitability: upper and lower 95% confidence intervals (C.I.)
    - the coefficient of variation (CV) among models.
  - Final run with confirming models
- Prediction of future tea/crop distribution.
- Identification of decisive growth factors.
  - Stepwise regression of suitability-shift per data point

Climate change summary of all study sites

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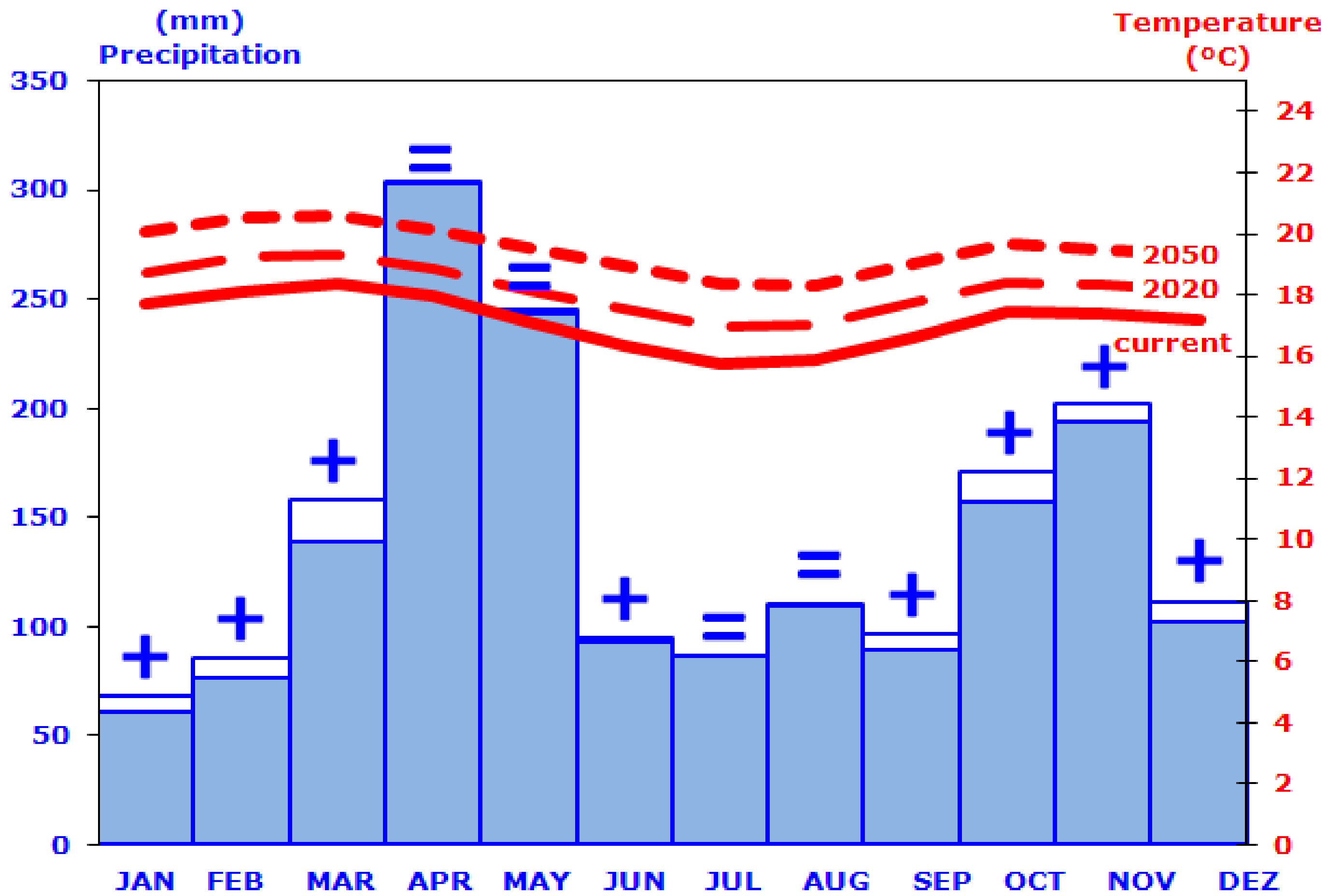

- The annual rainfall increases from 1658 millimeters to 1732 millimeters in 2050
- Temperatures increase and the average increase is 2.3 ºC passing through an increment of 1.0 ºC in 2020
- The maximum temperature of the year increases from 26.6°C to 29°C in 2050
- The minimum temperature of the year increases from 8.9°C to 11.1°C in 2050

Regional changes in the mean annual precipitation

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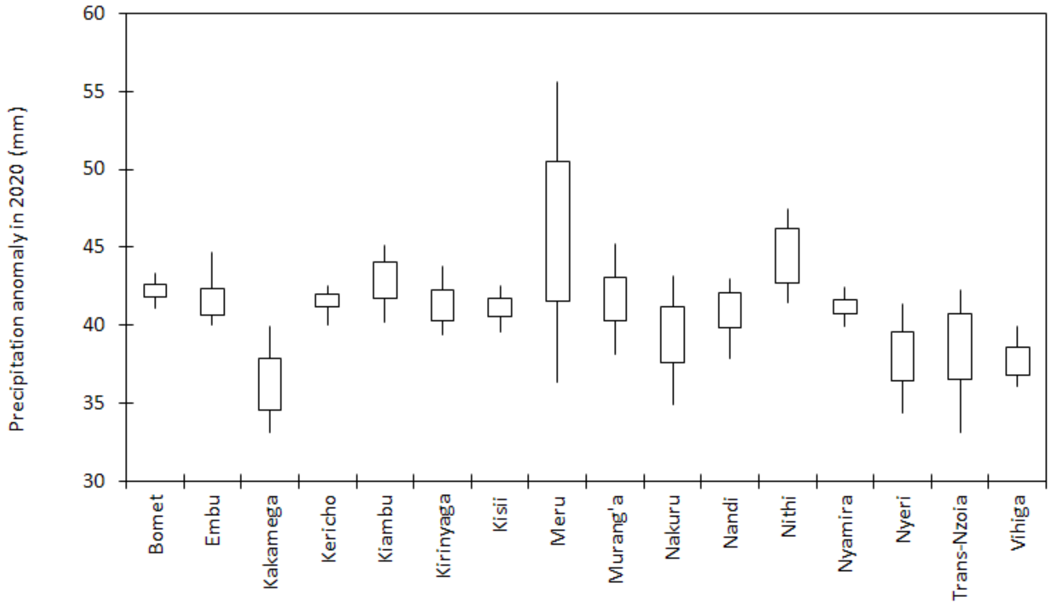
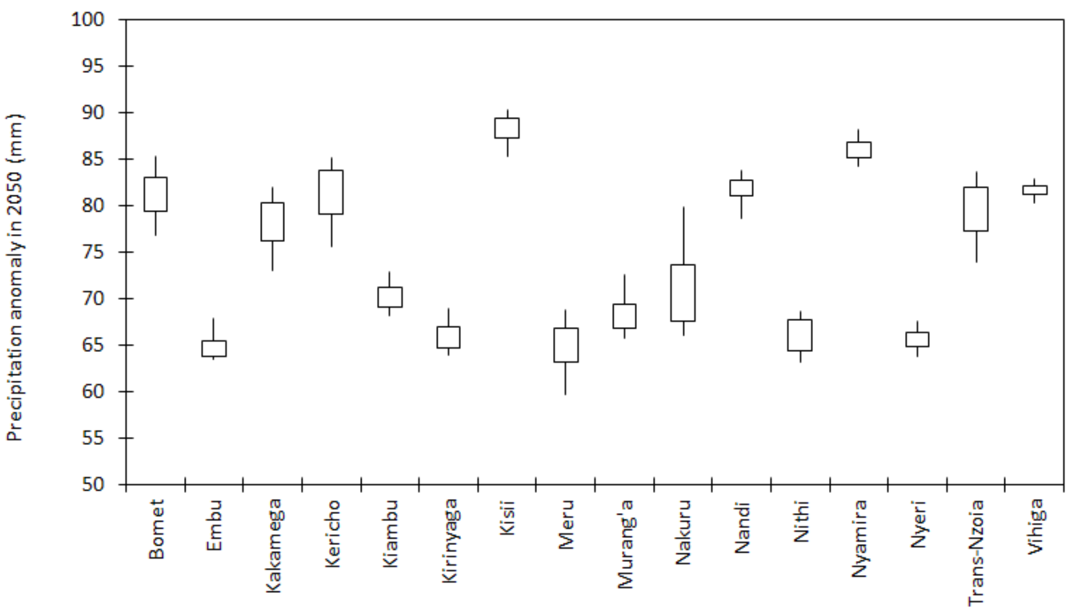


- In 2020 the municipalities Meru and Nithi will have larger increase in precipitation



- In 2050 Kisii and Nyamira will have the largest increase in precipitation

Regional changes in the mean annual temperature

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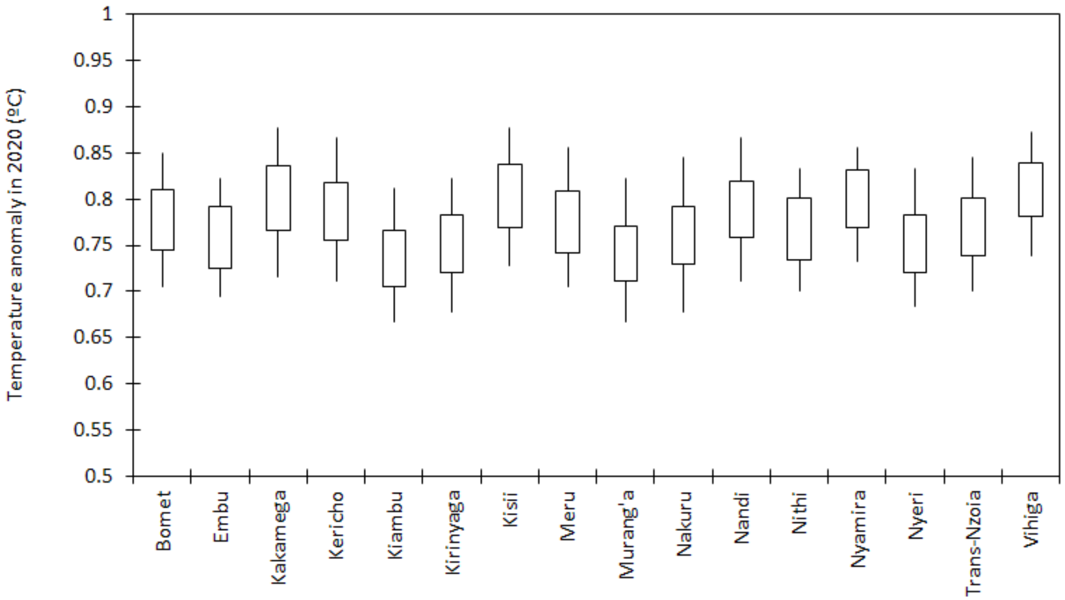
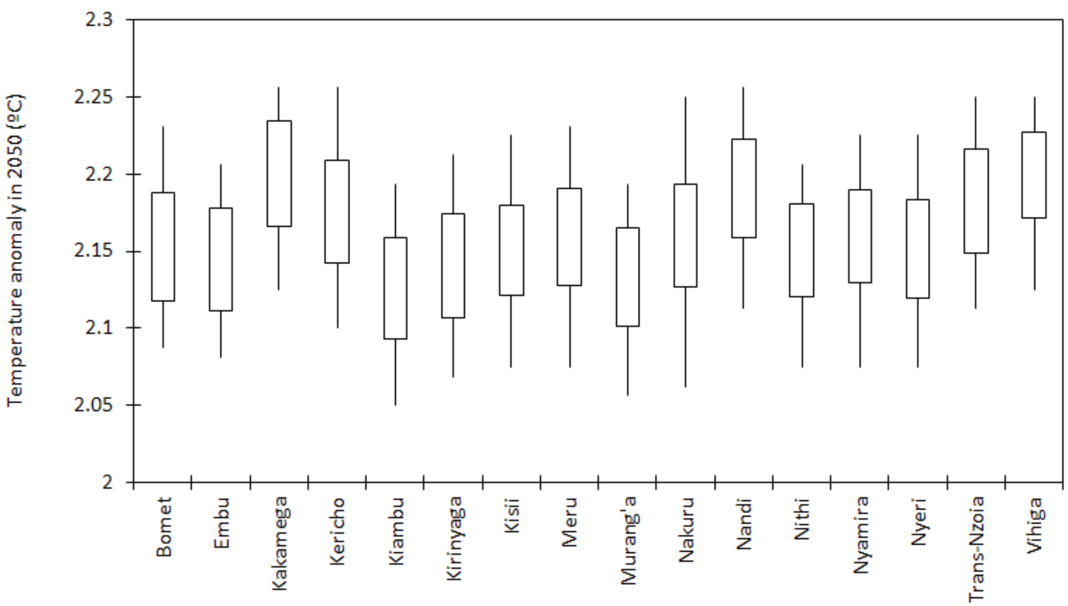


- The increase by 2020 is between 0.7 and 0.9 ºC



- The increase by 2050 is between 2.1 and 2.2 ºC

The mean annual temperature will increase progressively

Current suitability of tea production areas

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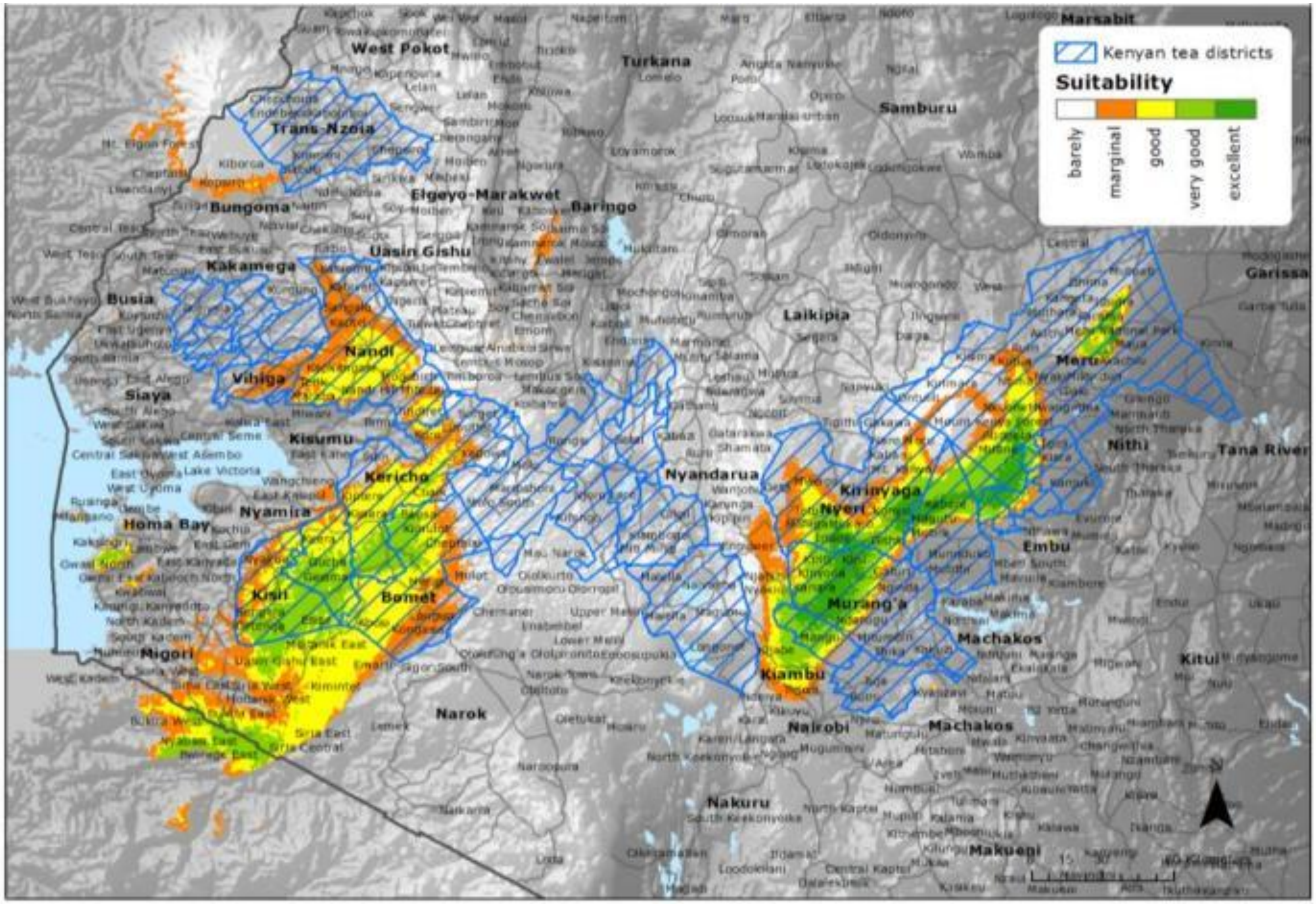

According to the MAXENT model, the most suitable of them are concentrated in the higher areas of districts: Meru, Embu, Kirinyaga, Nyeri, Murangá, Kiambu, Kisii, Nyamira, Kericho, Bomet, Narok, Migori and Homa Bay

Future suitability of tea production areas: 2020

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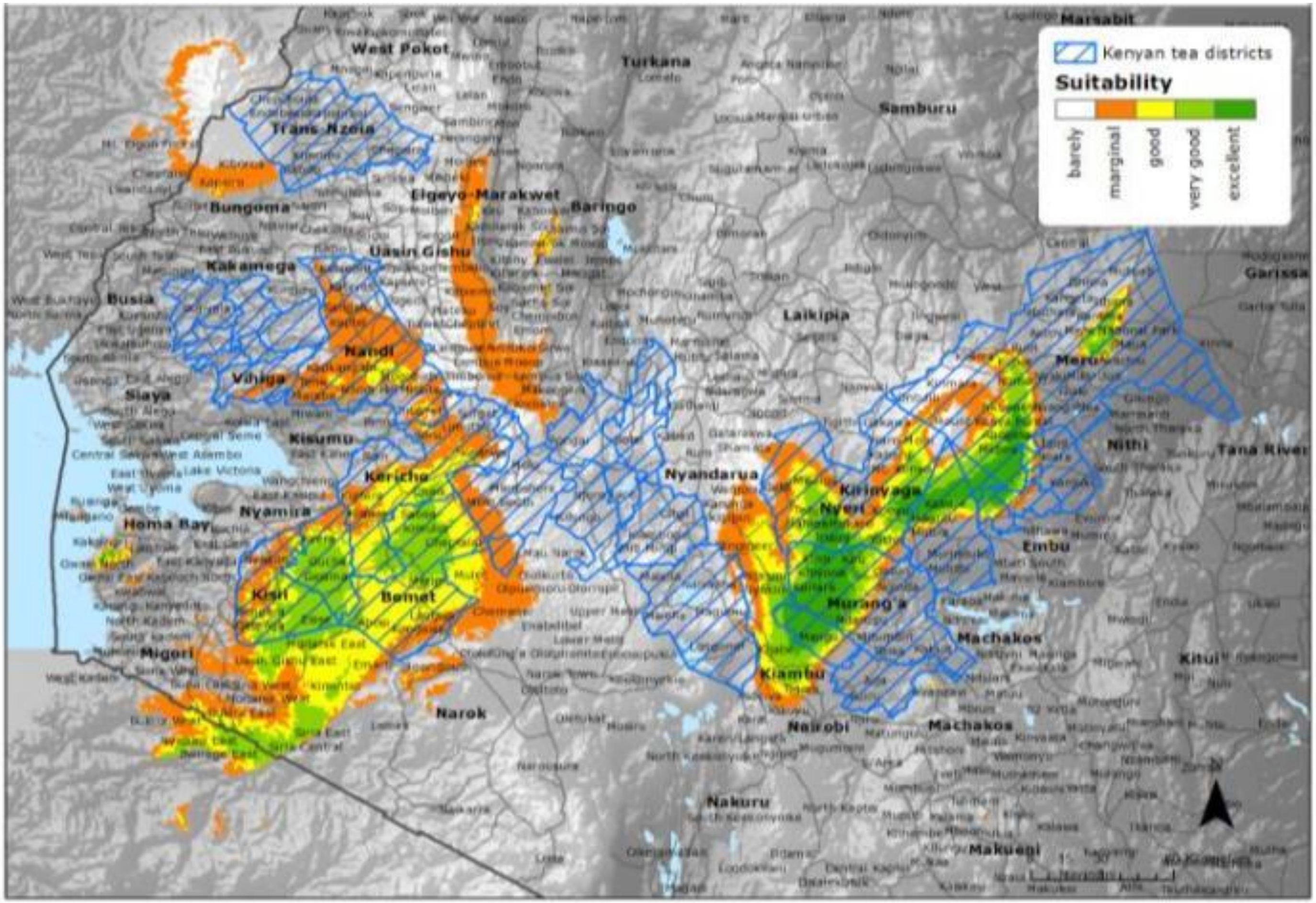

In 2020 suitable areas start shifting but the average suitability in all districts remain nearly constant

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Future suitability of tea production areas: 2050

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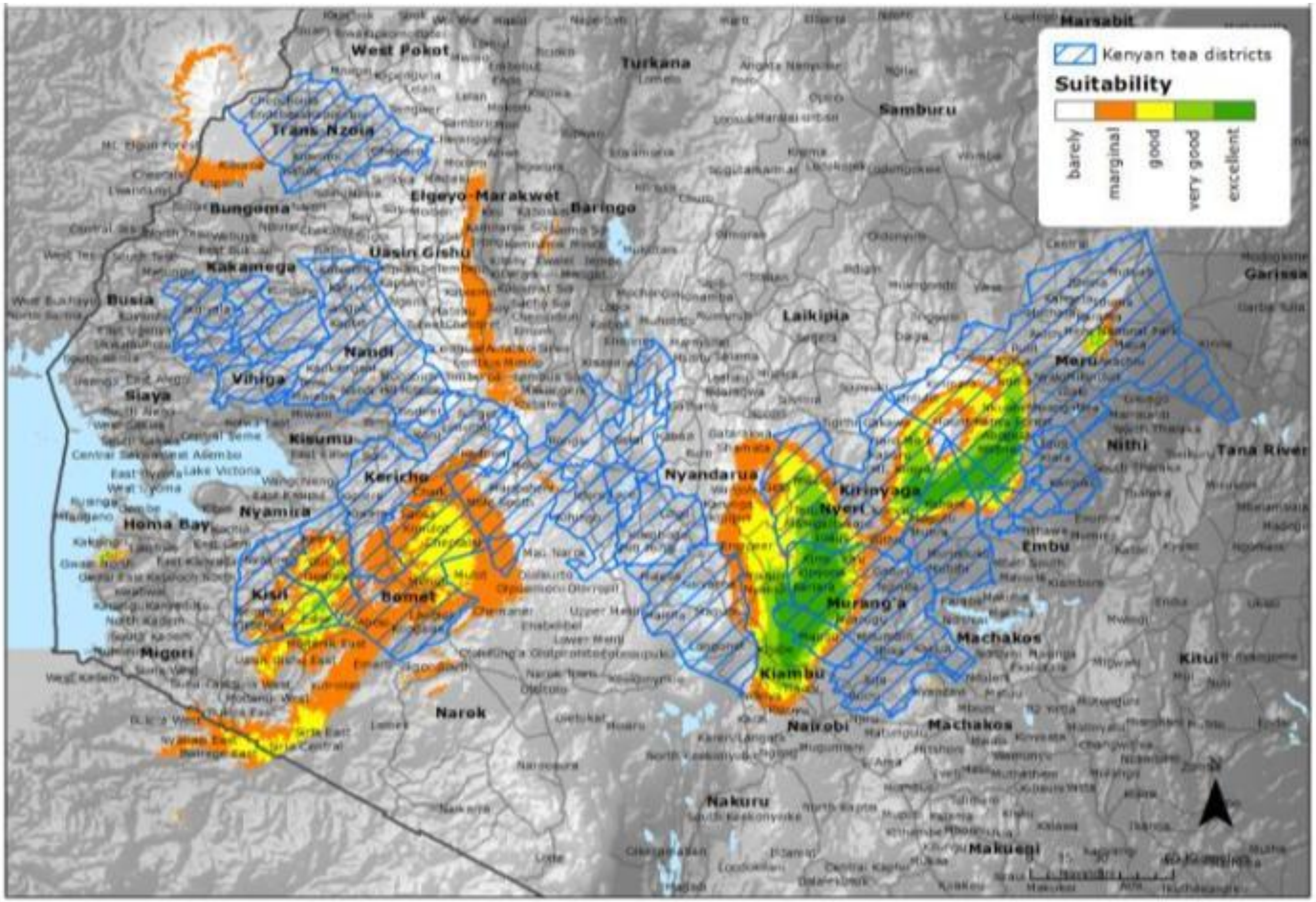

In 2050 tea production according to its climate-suitability is predicted to be more concentrated in Central Kenya

Suitability change of tea production areas

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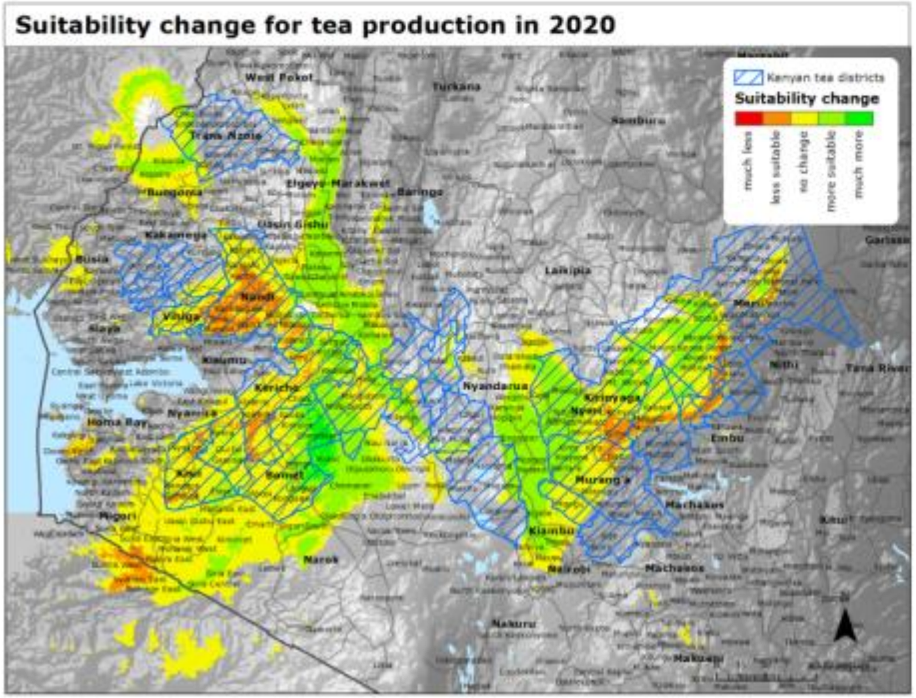

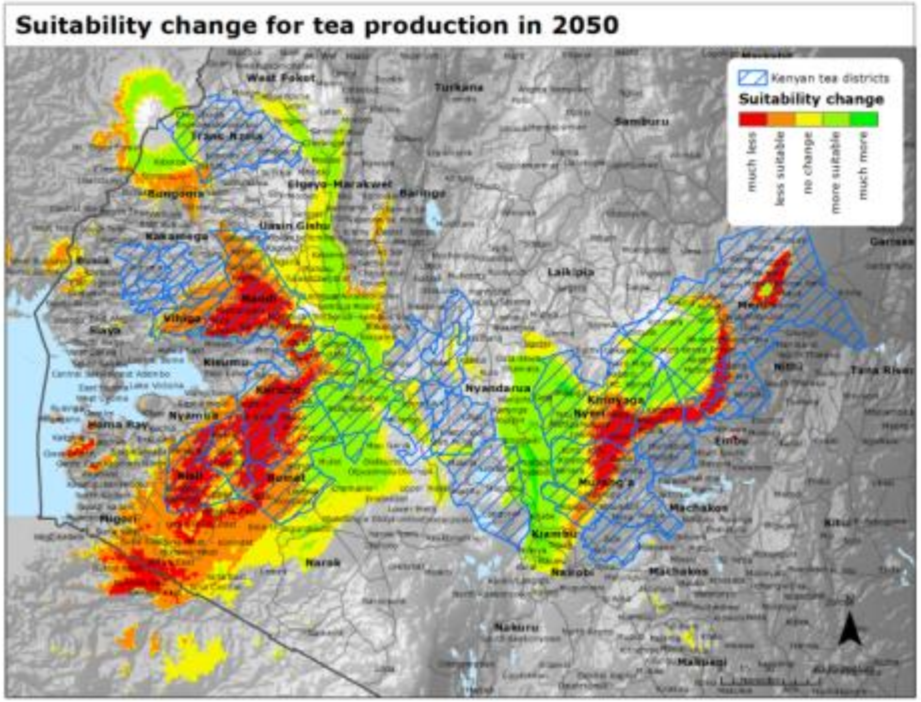

- Areas near Nandi suitability of tea shows a slight decrease by 2020
- Some areas, especially in Central region and some parts of Rift valley are gaining suitability
- In 2050 tea growing areas decreases quite seriously in the western parts
- Areas around Mount Kenya still remain on high suitability to climate in 2050
- General shift to higher altitudes
- Most significant loss of suitability (up to -40%) can be observed in Nandi district

Relation of suitability & altitude

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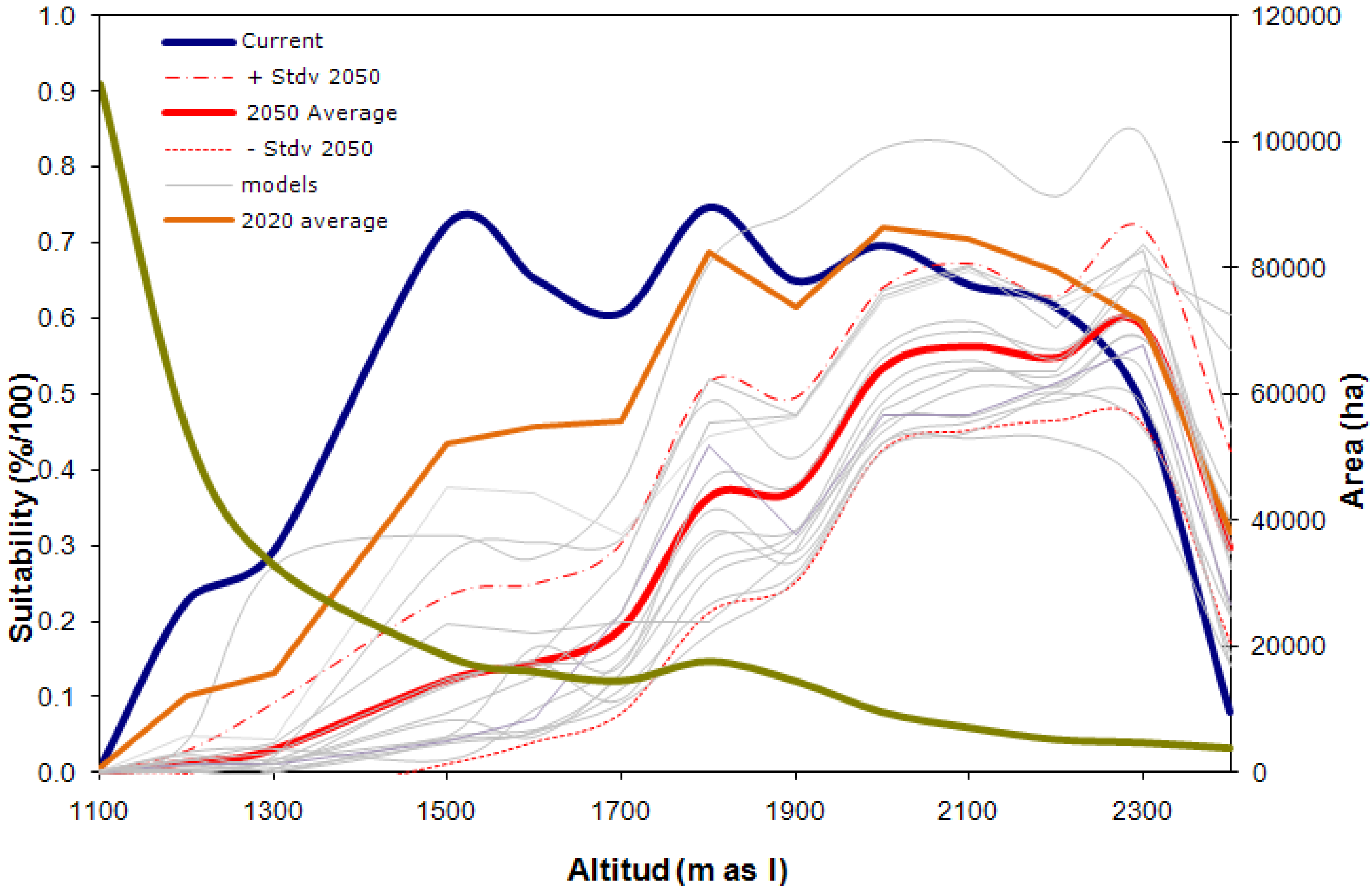
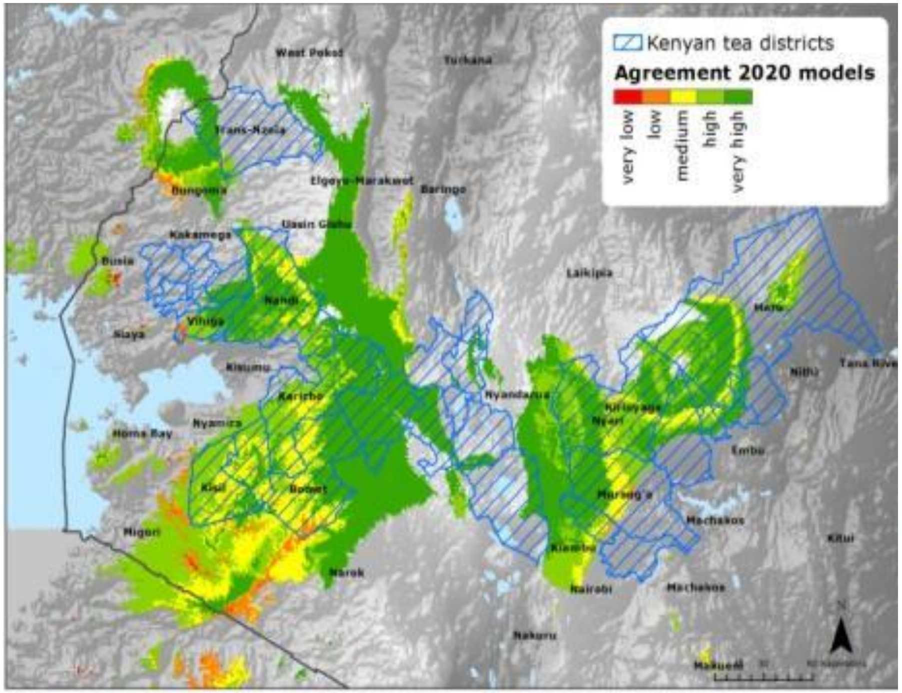
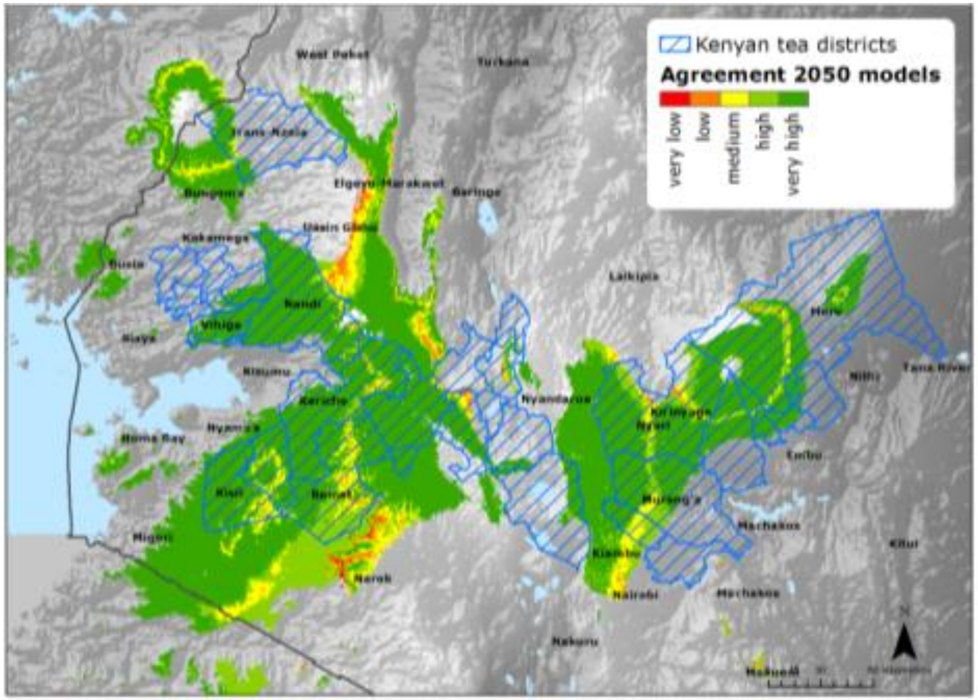


- With progressive climate change, areas at higher altitudes benefit on tea-suitability
- Optimum tea-producing zone is currently at an altitude between 1500 and 2100 masl
- By 2050:
  - suitability will increase to an altitude between 2000 and 2300 masl
  - areas at altitudes between 1400 and 2000 masl will suffer the highest decrease in suitability
  - areas around 2300 masl the highest increase in suitability

Measure of agreement of models predicting changes in the same direction as the average of all models at a given location





Coefficient of variance of bioclimatic variables

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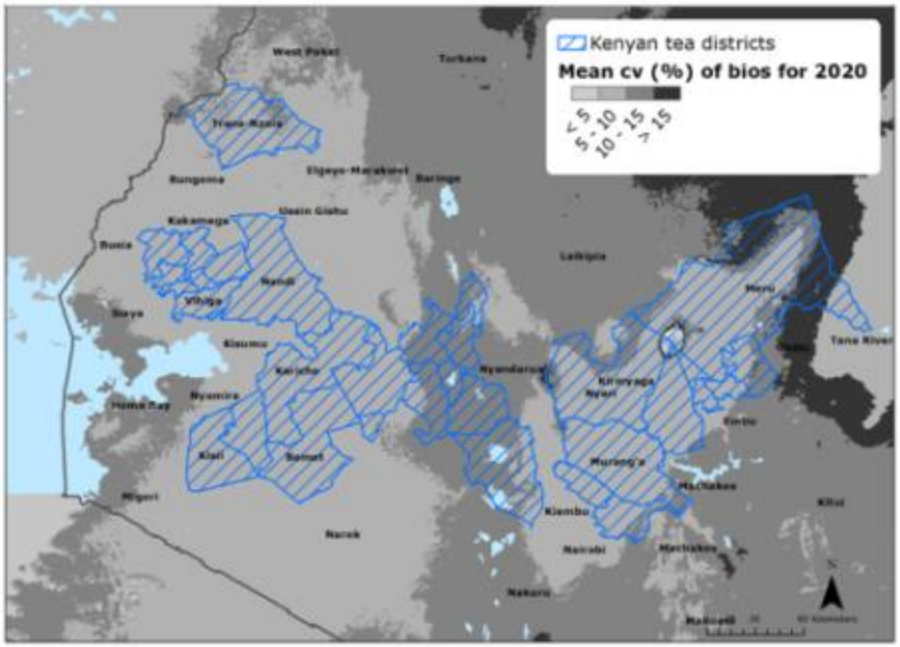

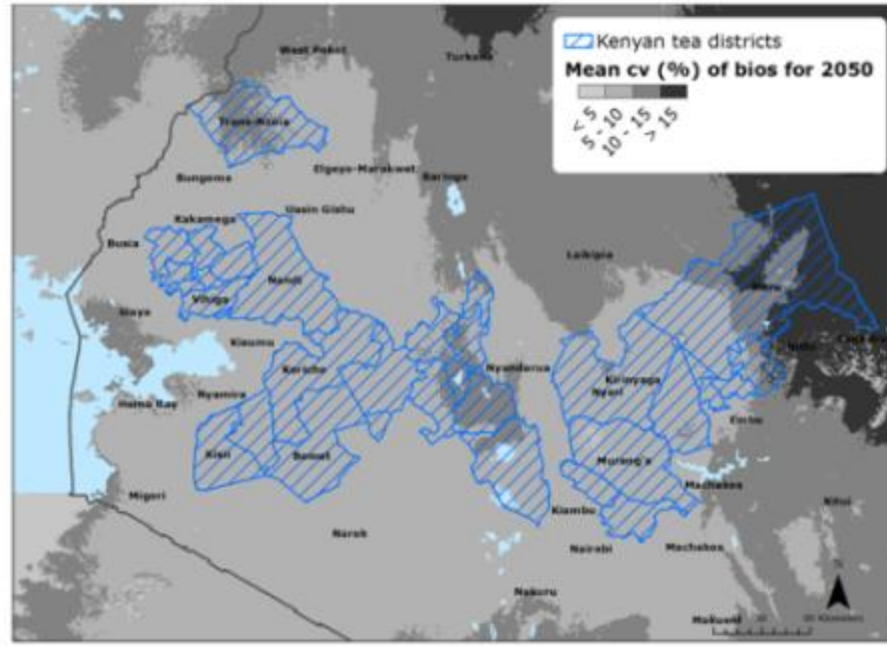

CV for 2020 and 2050 bioclimatic variables ranges between 0 and 15%, even lower for tea-growing areas and may therefore be accepted as reliable

- Stepwise regression for 2050 suitability-decreasing sites

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		

- Stepwise regression for 2050 suitability-increasing sites

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		

[a]Variables explaining less than 4% of total variability are not listed.

Identification of potential diversification strategies

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2020 *suitability change*	Tea	Coffee					Maize					Cabbage					Pea					Banana					Passion fruit				
much less	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
less suitable	12	-	-	90	10	-	-	-	100	-	-	-	-	100	-	-	-	-	-	90	10	-	-	-	-	-	-	-	20	40	40
no change	73	-	5	61	26	8	-	-	52	20	26	-	-	87	7	6	-	-	2	52	7	-	-	-	-	-	-	3	5	18	36
more suitable	15	-	38	39	15	8	-	-	15	38	38	-	-	62	23	15	-	-	-	23	-	-	-	-	-	-	-	-	-	15	8
much more	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

2050 *suitability change*	Tea	Coffee					Maize					Cabbage					Pea					Banana					Passion fruit				
much less	42	97	3	-	-	-	-	3	91	6	-	-	3	97	-	-	-	-	-	3	97	-	-	-	14	9	14	6	11	14	51
less suitable	21	94	6	-	-	-	6	-	50	33	11	6	-	94	-	-	-	-	6	-	94	-	-	-	28	-	-	6	-	11	78
no change	25	57	43	-	-	-	-	-	5	5	90	-	-	67	19	14	-	-	-	24	62	-	-	-	5	-	-	-	-	14	24
more suitable	12	10	70	20	-	-	-	-	-	20	80	-	-	40	-	60	-	-	-	-	40	-	-	-	-	-	-	-	-	-	10
much more	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Coffee performs similar (even worse) to tea and *would not be a good alternative* crop to tea. While on 42% of all tea factory sites suitability of tea is predicted to be much less for 2050, on 97% of these sites suitability of coffee will be also much less, for more than 90% of these sites **maize** and **cabbage** will *remain constant* and **pea** will be *much more suitable* on 97% of this sites. **Passion-fruit** will be *much more suitable* on 51% of this sites and **banana** on 14% of these sites *more suitable for 2050*.

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2050 Change of suitability of diversification crops

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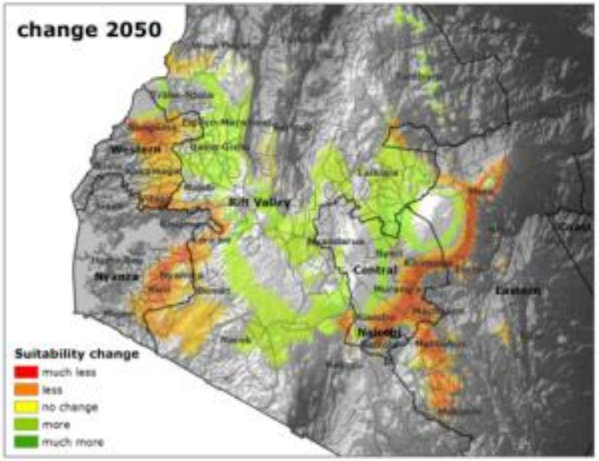
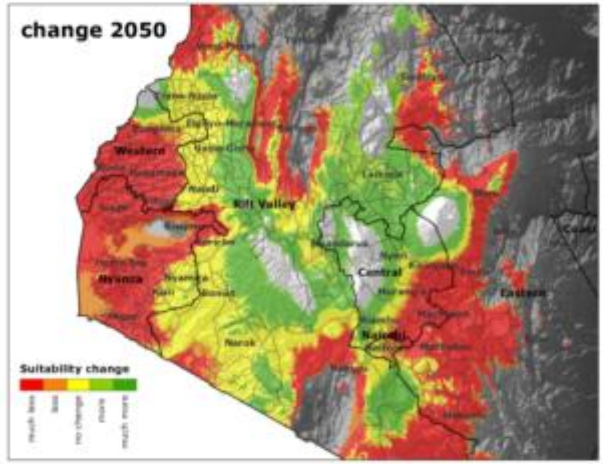
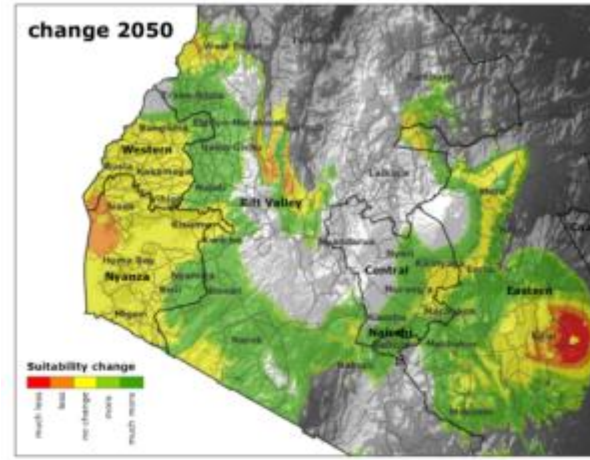
Coffee



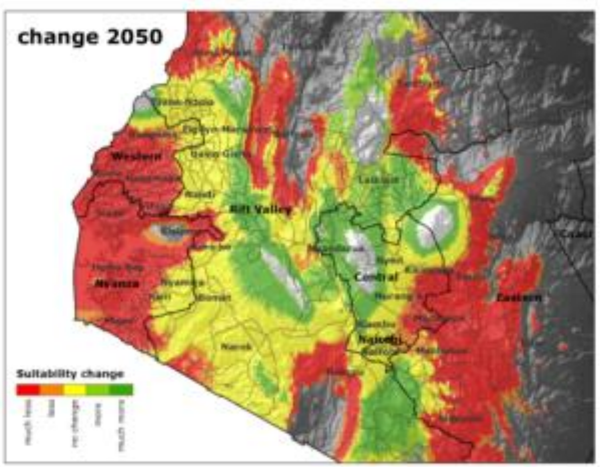
Maize



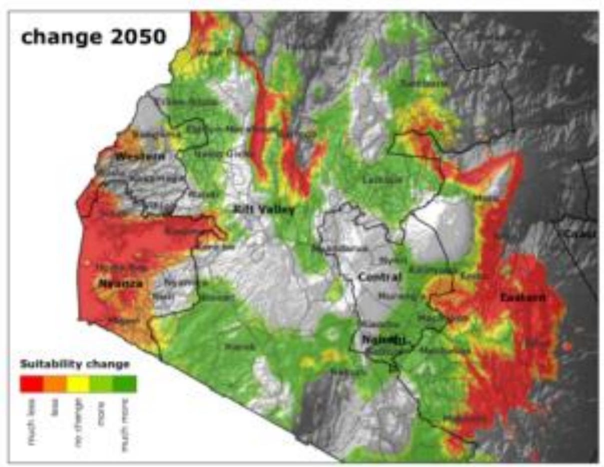
Pea



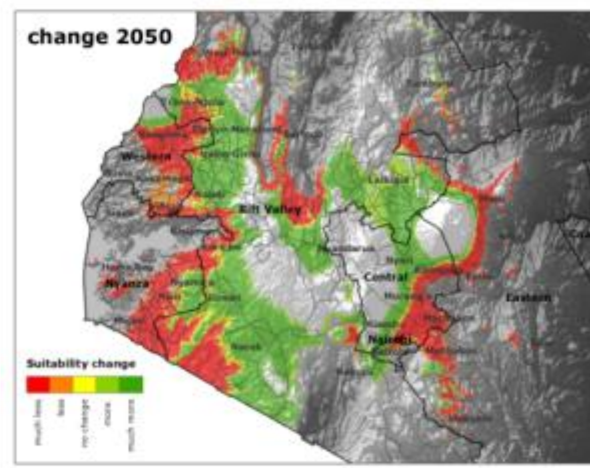
Cabbage



Banana



Passion-fruit



Conclusions

- In Kenya 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's within the current tea-growing areas in Kenya for tea production in general will decrease quite seriously by 2050.
- The optimum tea-producing zone is currently at an altitude between 1500 and 2100 masl and will by 2050 increase to an altitude between 2000 and 2300 masl.
- Compared with today, by 2050 areas at altitudes between 1400 and 2000 masl will suffer the highest decrease in suitability and the areas around 2300 masl the highest increase in suitability.
- A comparison of potential diversification crops recommended by the project show that coffee perform similar to tea and would not be a good alternative crop. For more than 90% of these sites maize and cabbage will remain constant and pea will be much more suitable on 97% of this sites. Passion fruit will be much more suitable on 51% of this sites and banana on 14% of these sites more suitable for 2050.

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