Predicting the Impact of Climate Change on the Cocoa-Growing Regions in Ghana and Cote d'Ivoire

Final report
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CLIMATE CHANGE AGRICULTURE AND FOOD SECURITY

CIAT
Centro Internacional de Agricultura Tropical
International Center for Tropical Agriculture
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List of Acronyms

BIOCLIM	Bioclimatic analysis and prediction system
BMGF	Bill and Melinda Gates Foundation
CIAT	International Center for Tropical Agriculture
CV	Coefficient of variation
DAPA	Decision and Policy Analysis
ESG	Earth System Grid
FAO	Food and Agriculture Organization
GARP	Genetic algorithm for rule-set production
GBIF	Global Biodiversity Information Facility
GCM	Global circulation model
GHCN	Global Historical Climatology Network
GPS	Global position system
IPCC	Intergovernmental Panel on Climate Change
masl	Meters above sea level
MAXENT	Maximum entropy
NWP	Numerical weather prediction
R-HYdroNET	Regional electronic hydrometeorological data network (for Latin America and the Caribbean)
SPAM	Spatial production allocation model
SRES	Special report on emissions scenarios
SRTM	Shuttle radar topographic mission
WMO	World Meteorological Organization

1 Authors and contact details

The analyses presented here were conducted by the Decision and Policy Analyses (DAPA) program at the International Center for Tropical Agriculture (CIAT) under the leadership of Dr. Peter Läderach, with the collaboration ofAnton Eitzinger, Armando Martínez and Narioski Castro. The compilation of the ground data has been facilitated through Agro Eco - Louis Bolk Institute in Ghana.

For further information please contact:

Dr. Peter Läderach
International Center for Tropical Agriculture (CIAT)
Hotel Seminole, dos cuadras al Sur
Managua, Nicaragua
Email: p.laderach@cgiar.org

2 Executive summary

This document is one of three reports on the methods and results of a consultancy with the title "Predicting the impact of climate change on cocoa, cashew and cotton growing regions in Ghana and Cote d'Ivoire" conducted by the International Center for Tropical Agriculture (CIAT) for the Bill and Melinda Gates Foundation (BMGF).This report focuses on cocoa but summarizes the impact of climate change on all three crops in chapter 9. It aims to inform the private-public partnership (PPP) project titled "Cocoa Livelihoods Project" (CLP) and the cocoa sector in particular, but all supply chain actors in other sectors as well.

The objective of the research was to generate future climate scenarios to predict the impact of climate change on the suitability to grow cocoa of the main growing regions of Ghana and Cote d'Ivoire.

The applied methodology is based on the combination of current climate data with future climate change predictions from 19Global Circulation Models for 2030 and 2050. The data of the current and the future climates were used as input to MAXENT, a crop prediction model. The evidence data used for MAXENT were collected in field missions, shared by partners in Ghana and Côte d'Ivoire and from the literature.

The analysis focused on the specific regions where cocoa is currently-grown. The study used predictions of the future climate to predict the suitability of current cocoa-growing areas to continue growing it by 2030 and 2050.

The current optimum altitude for cocoa is 100–250 meters above sea level (masl), which will increase to 450–500 masl by 2050, compensating for the increase in temperature due to a climate change.

Worldwide, large cocoa plantations are in regions where the mean temperature ranges from 22–25°C. In the cocoa-growing areas of the Brazilian Amazon for example, temperatures are 22–30°C(Dias, 2001),while in Ghana's cocoa-growing regions they are 24–29°C(Dormon et al., 2004).

The changes in suitability as climate change occurs are site-specific. There will be areas that become unsuitable for cocoa (Lagunes and Sud-Comoe in Côte d'Ivoire), where farmers will need to identify alternative crops. There will be areas that remain suitable for cocoa, but only when the farmers adapt their agronomic management to the new conditions the area will experience. There will also be areas where suitability of cocoa increases (Kwahu Plateu, between Eastern and Ashanti regions in Ghana). Finally, there will be areas where today no cocoa is grown but which in the future will become suitable (18 Montagnes in Côte d'Ivoire). We did not consider using the protected areas (such as forest reserves) as available for cocoa cultivation, however, to avoid promoting clearing forests or invasion of protected areas for new cocoa areas. Climate change brings not only bad news but also a lot of potential opportunities. The winners will be those who are prepared for change and know how to adapt.

3 Background and Objectives

We analyzed the impact of climate change on cocoa production in Ghana and Côte d'Ivoire. In 2008/2009 world cocoa production was aboutUS$9 billion (ICCO, 2008). Ivory Coast, with 2.4 Mha under cocoa, and Ghana (1.5 Mha) between them produce 53% of the world's cocoa (ICCO, 2008; Franzen and Borgerhoff Mulder, 2007). Ghana produces high-quality cocoa that earns a premium price on the world market.

Cocoa is an important cash crop in both countries, contributing 7.5% of GDP in Côte d'Ivoire and 3.4% in Ghana (FAO, 2008). It accounts for 70-100% of household incomes of cocoa farmers in Ghana (Ntiamoah and Afrane, 2008). Any impact of climate change on the suitability to grow cocoa in West Africa will not only affect farmers' livelihoods and incomes, but the national economies as well. Half the cocoa in Ghana and Côte d'Ivoire is grown under low shade, which is a sustainable land use practice with ecological, biological and economics benefits (Asare, 2006).

The International Center for Tropical Agriculture (CIAT) contracted with the Bill and Melinda Gates Foundation (BMGF) to "Predict the impact of climate change on the cocoa-, cashew- and cotton-growing regions in Ghana and Cote d'Ivoire". This paper, one of three, reports on cocoa, with the primary aim of informing a private-public partnership (PPP) project titled "Cocoa Livelihoods Project" (CLP) and the cocoa sector in particular, but also supply-chain actors in the other sectors. All three papers are summarized in Chapter 9.The paper includes climate predictions, predictions of crop climate suitability, and detailed analyses for the cocoa-growing areas in Ghana and Cote d'Ivoire(Figure 1).

The objectives of this study were:

To determine which environmental variables drive the climate suitability of an area to grow cocoa;

To predict the change in climate for the cocoa-growing areas in Ghana and Côte d'Ivoire; and

To predict the impact of progressive climate change on the suitability of the current growing area in Ghana and Côte d'Ivoire to continue producing cocoa.

Figure 1: Ghana and Côte d'Ivoire cocoa growing-areas.Data collected using GPS (yellow dots), land-use data (orange dots) and expert knowledge during the summit (green dots).

4 Methodology

4.a Current climate

For the 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., 2005).

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[1]).

[1] 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 – 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

4.b Future climate

Predictions of future climate

The Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report was based on the results of 21 global circulation models (GCMs), produced in a number of specialized atmospheric physics laboratories around the world. The spatial resolution of the GCM results is inappropriate for analyzing the impacts of climate change 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 highly mountainous areas, where, in some places, one cell can cover the entire width of the mountain 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 forecast more accurately. The method basically produces a smoothed (interpolated) surface of changes in climates, which is then applied to the baseline climate taken from WorldClim. The method assumes that changes in climates are only relevant at coarse scales, and that relationships between variables are maintained towards the future (Ramírez and Jarvis, 2010).

CIAT downloaded the data from the Earth System Grid (ESG) data portal and applied the downscaling method to 19 GCMs for the emission scenario SRES-A2 from the IPCC's Special Report on Emission Scenarios (SRES) and for two different 30-year running mean periods (i.e. 2020–2049 [2030s], 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 (Ramírez and Jarvis, 2010).

4.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 the 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). Similar to logistic regression, MAXENT weights each environmental variable by a constant. The probability distribution is the sum of each weighted variable divided by a scaling constant to ensure that the probability value ranges from 0–1. The algorithm 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 method for this sort of analysis (Elith et al., 2006).

Data collection and model calibration

For the future predictions we required evidence data of current distribution of cocoa production. The evidence data was compiled through existing databases, maps, expert knowledge, and field missions using a Global Positioning System (GPS). In addition, we reviewed the literature to identify main growing areas for cocoa in both countries. For some areas the collected data was insufficient to determine the spatial distribution of the growing areas and we used land cover and maps of potential land use based on soil characteristics (Dabin et al., 1960) to identify current cocoa-growing areas.

Two hundred and thirty-five points were collected during afield mission using GPS and 59 points were identified through potential land use. We did this by overlapping the layers of land cover and potential land use, plus the opinions of experts in the area. We used a total of 294 coordinates in the analysis.

After some trial runs of the MAXENT procedure, we asked local experts to validate the predictions (Annex I). We incorporated these experts' opinions and reran MAXENT. We presented the results in a cocoa summit representing the cocoa sector and supply chain (see annex III for the list of attendees) in Accra, Ghana on 6 April, 2011. We incorporated participant´s feedback and reran MAXENT for the final analysis.

Suitability ranges

Climate suitability is the level of certain climatic characteristics that determine which areas have potential to grow a crop successfully. For the cocoa study we used the bioclimatic variables, calculating the suitability ranges from the MAXENT results, which provide suitability estimates 0–1 for each variable. During the summit, we asked experts to comment on a map of the MAXENT estimates by placing colours according to their own estimates of the suitability of areas for cocoa (Table 1).

Table1: Categories used for the map.

MAXENT Range	Category	Color in map
0 – 0.15	Barely	No color
0.15 – 0.25	Marginal	Orange
0.25 – 0.35	Good	Yellow
0.35 – 0.40	Very Good	Light green
0.40 – 0.85	Excellent	Green

Spatial restrictions

The MAXENT analyses only included climatic variables, but in the field there are many spatial restrictions as well, which are natural, such as forest and water bodies, and anthropogenic, such as urban areas. We excluded urban and water bodies as well as forested and protected areas as not available for cocoa, using the 300-m resolution FAO land cover map (Geonetwork), and shapefiles from the world database on protected areas (IUCN and UNEP,2010).

4.d Measure of confidence

We predicted future crop suitability using each of the GCMs using MAXENT as described above. We computed two measurements of uncertainty: (1) The coefficient of variation (CV) among GCMs and(2) the agreement among MAXENT outputs calculated as the percentage of models predicting changes in the same direction as the average of all models at a given location. We removed from further analysis any GCM that differed significantly according to Tukey's (1977) outlier test.

4.e Environmental factors driving change in suitability

We determined the relative importance of different climatic drivers, using 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. We calculated the relative contribution that each variable made to the total predicted shift in suitability in terms of the proportion of R-square explained when each variable was added to the regression model. We analyzed separately data points showing positive and negative shifts in suitability.

5 Result I: Climate change summary of cocoa growing areas

5.a The summary climate diagram for all cocoa growing sites in Ghana and Côte d'Ivoire

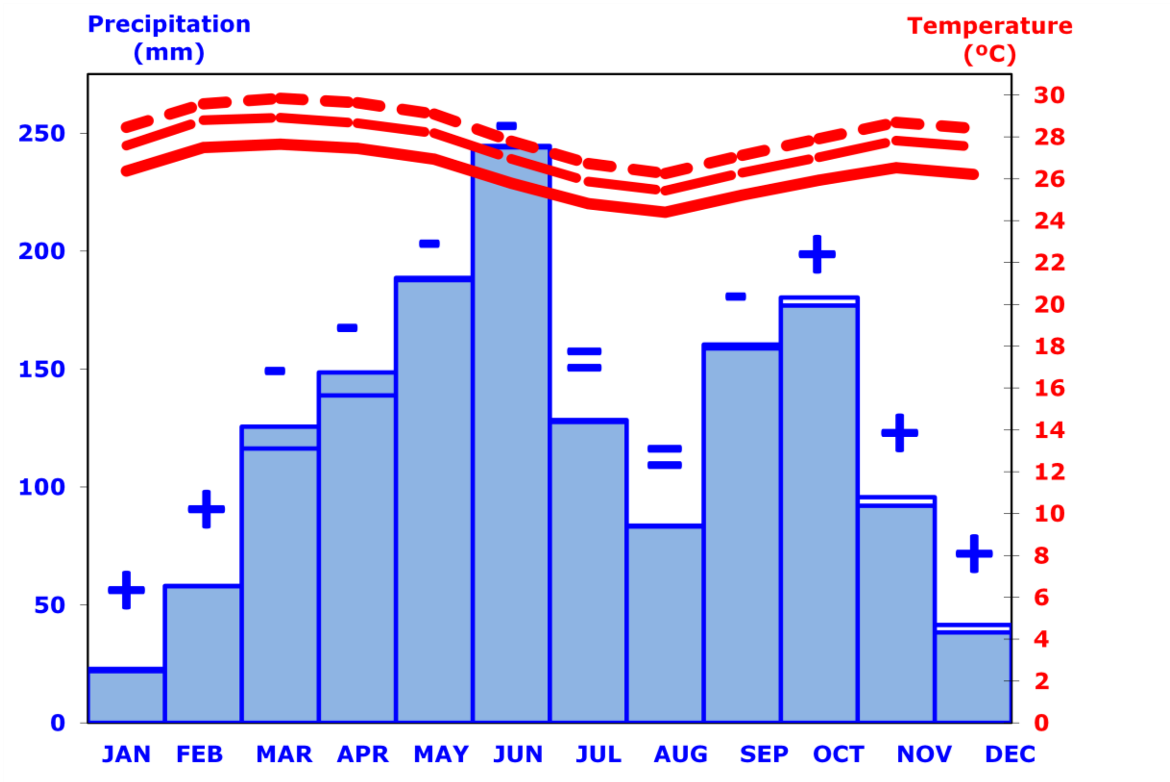

Figure 2: Climate trend summary for 2030 and 2050 for sample sites.We used 294 evidence points in the analysis. Blue bars show current and 2050 precipitation trends and red lines show the current, 2030 and 2050 temperature.

General climatic characteristics

- Temperatures increase and the average increase is 2.1°C for 2050 passing through 1.2°C in 2030
- The mean daily temperature range decreases from 9.1°C to 9.0°C in 2050
- Rainfall decreases slightly from 1467 millimeters to 1455 millimeters by 2050 passing through 1466 in 2030. The amount of the decrease is so small that it can be safely ignored.
- The maximum number of cumulative dry months decreases from 4 months to 3 months in 2050

Extreme conditions

- The mean monthly maximum temperature increases from 33.1°C to 35.6°C while the warmest quarter gets hotter by 2.3°C in 2050;
- The mean monthly minimum temperature increases from 20.6°C to 22.2°C while the coldest quarter gets hotter by 1.7°C in 2050;

- Changes in the wettest month and the wettest quarter are trivial (<5mm); and
- There is no change in the driest month or in the driest quarter.

Climate Seasonality

- Overall the climate becomes more seasonal in terms of variability through the year in temperature and the seasonality of precipitation is unchanged.

Variability between models

- The coefficient of variation of temperature predictions between models is 3%;
- Temperature predictions were uniform between models with no outliers;
- The coefficient of variation of precipitation predictions between models is 7.5%; and
- Precipitation predictions were uniform between models with no outliers.

5.b Regional changes in the mean annual precipitation by 2030

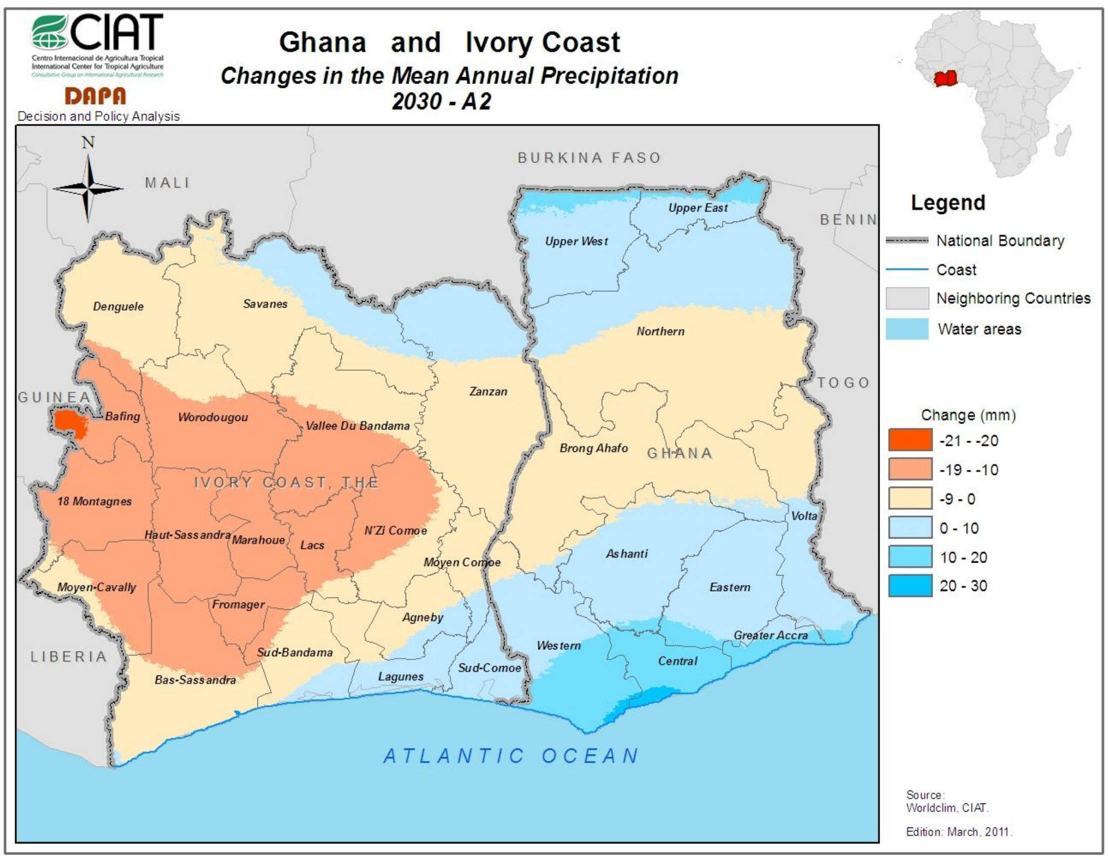

Figure 3: Mean annual precipitation changes by 2030 according nineteen GCM models (SRES A2) for Ghana and Côte d'Ivoire.

According to the SRES scenario A2 (business as usual) there will be small increases and decreases in precipitation by 2030 (Figure 3), but given the relatively high annual precipitation in the cocoa-growing regions of both countries, the changes can be safely ignored.

5.c Regional changes in the mean annual precipitation by 2050

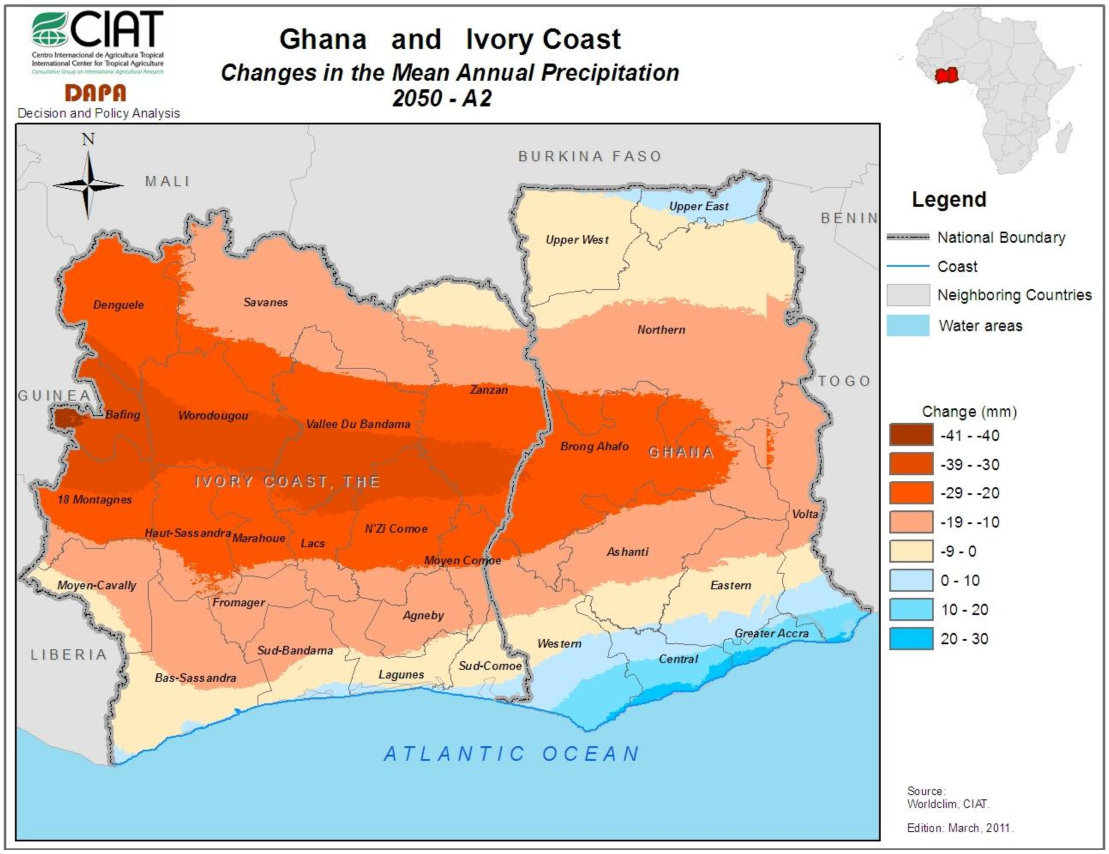

Figure 4: Mean annual precipitation changes by 2050according to nineteen GCM models (SRES A2) for Ghana and Côte d'Ivoire.

The predictions for precipitation by 2050 indicate a slight decrease in the central regions of both countries while the coastal regions in Ghana will be wetter by 20 mm to 30 mm.

5.d Regional changes in the mean annual temperature by 2030

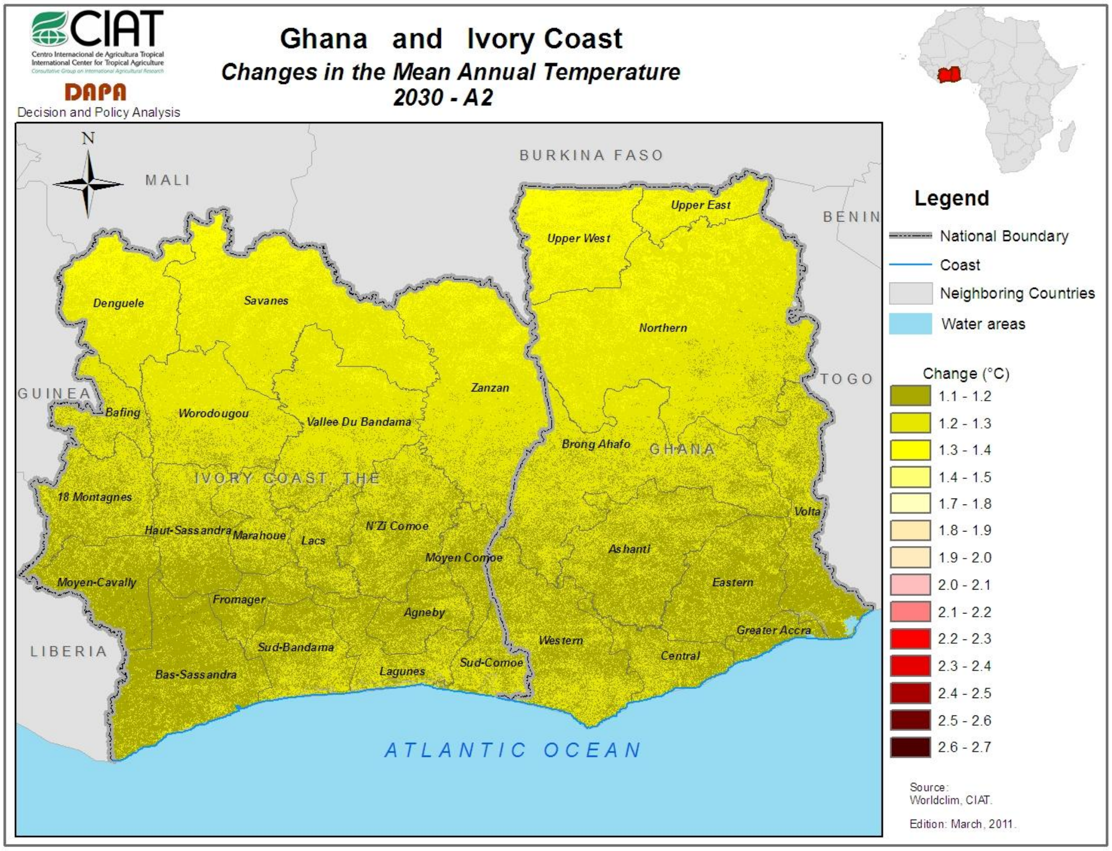

Figure 5: Mean annual temperature changes by 2030according nineteen GCM models (SRES A2) for Ghana and Côte d'Ivoire.

Temperature will increase by 2030 by 1.1–1.3°C (Figure 5) for the southern regions and up to 1.4°C for the northern regions in both countries.

5.e Regional changes in the mean annual temperature by 2050

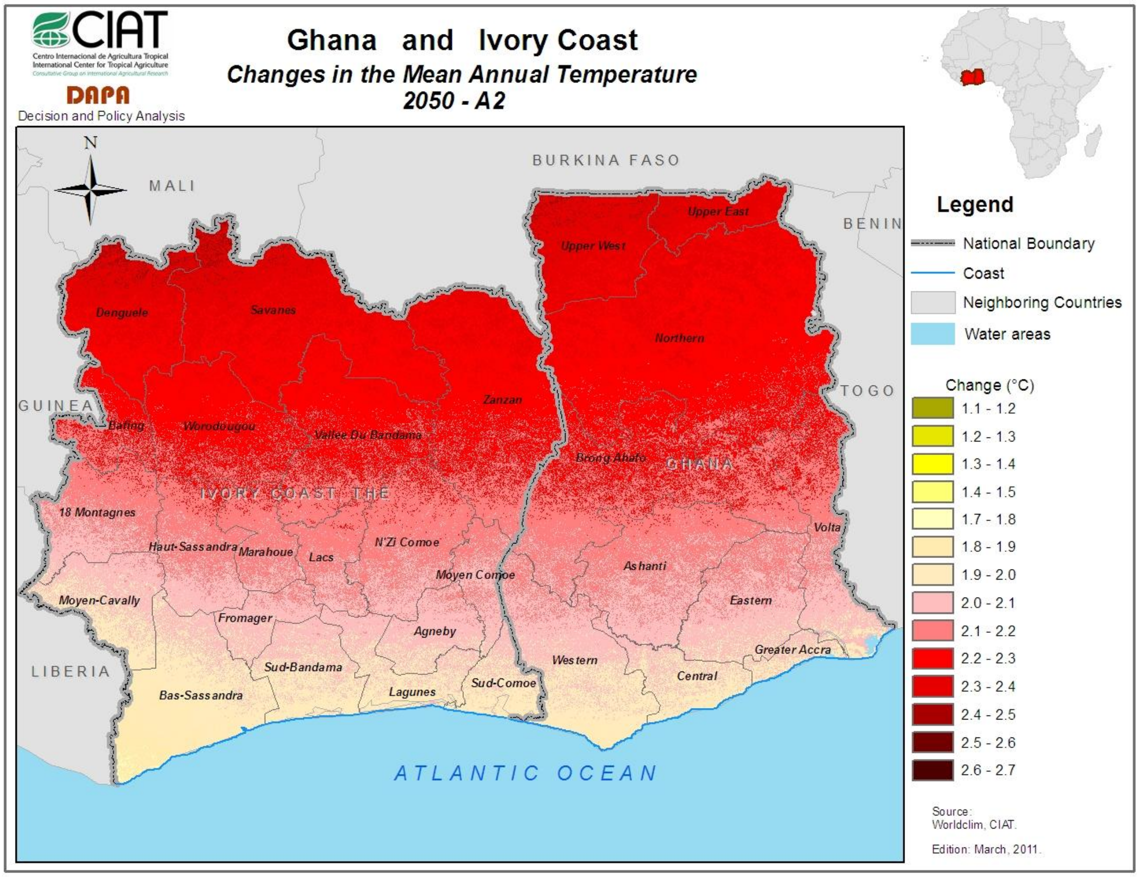

Figure 6: Mean annual temperature changes by 2050 according to nineteen GCM models (SRES A2) for Ghana and Côte d'Ivoire.

The mean annual temperature will increase progressively by 2050 by 1.7–2.1°C in the southern regions, and up 2.5°C to the northern regions.

6 Result II: Suitability maps of cocoa growing areas

In Ghana and Côte d'Ivoire the yearly and monthly rainfall will decrease slightly by 2050, except for coastal areas in Ghana, but the yearly and monthly minimum and maximum temperatures will increase by 2030 and continue to increase by 2050. Overall climates becomes less seasonal in terms of variation throughout the year with temperature in specific districts increasing by about 1.2°C by 2030 and 2.1°C by 2050 and less seasonal in precipitation with the number of dry months decreasing from 4 to3 months. The implications are that the distribution of suitability within the current cocoa-growing areas in Ghana and Côte d'Ivoire in general will decrease quite seriously by 2050 because of the temperature increases.

Increased temperatures will increase evapotranspiration of the cocoa trees. The increase of the maximum temperature of the warmest month and annual temperature range (bios 5 and 7, both of which represent 49% of the total variability) will impact negatively in cocoa-growing regions by 2050 (see Chapter 7 for more details).

6.a Current suitability of cocoa growing areas

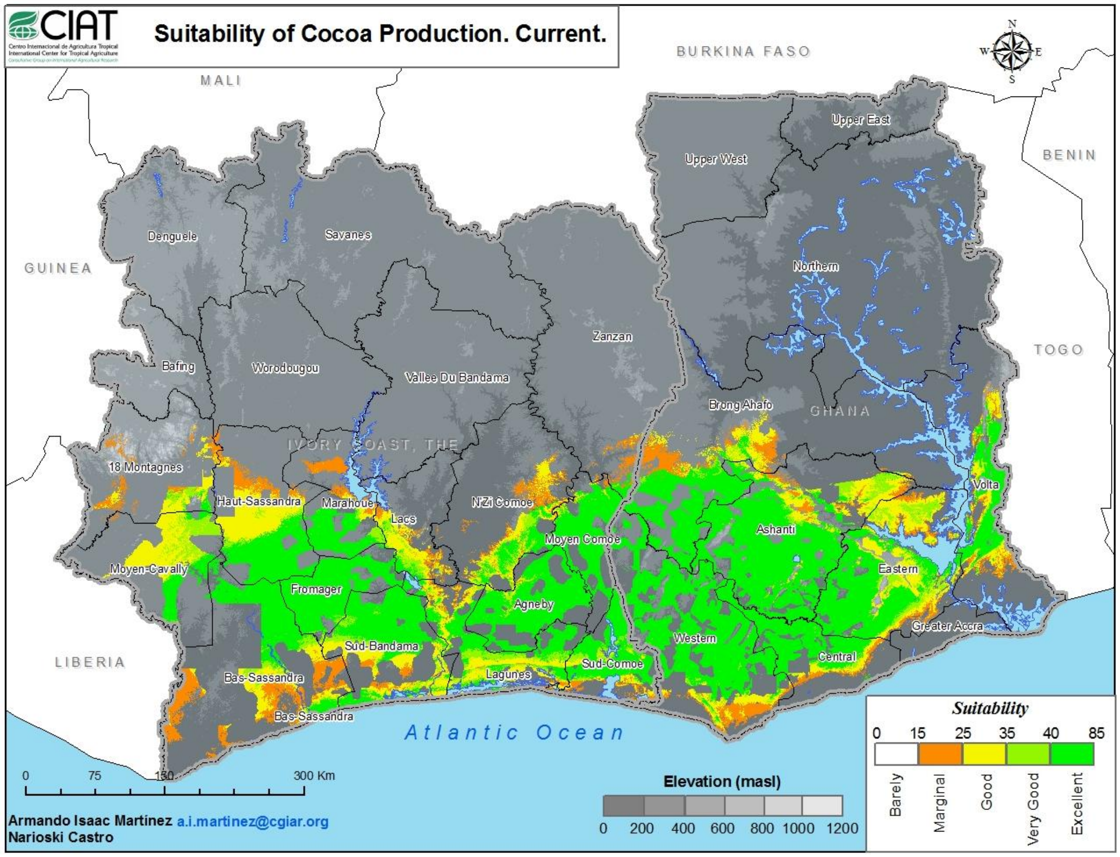

Figure 7: Current suitability for cocoa production within cocoa-growing regions of Ghana and Côte d'Ivoire.The grey areas inside the suitable areas are protected areas not available for cocoa production.

Currently, the main cocoa-producing areas in both countries are located in the rainforest eco-zone (MOFA, 2010). In Ghana, they are mainly in the Eastern, Central, Ashanti, Western and south of Brong Ahafo regions and in Côte d'Ivoire they are mainly in Sud-comoe, Agneby, Moyen Comoe, Sud-Bandama and Fromager regions (Figure 7). According to the MAXENT analysis, the most suitable areas match with the semi-deciduous rainforest eco-zone.

6.b Future suitability of cocoa growing areas

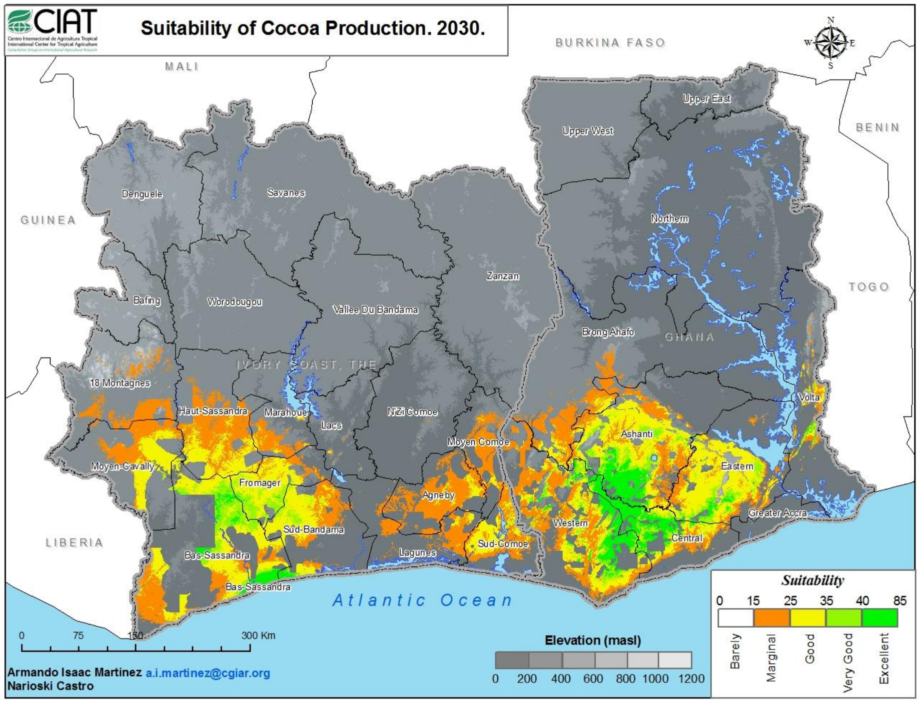

Figure 8: Suitability for cocoa production in 2030 according to 19 GCM using MAXENT crop prediction model.

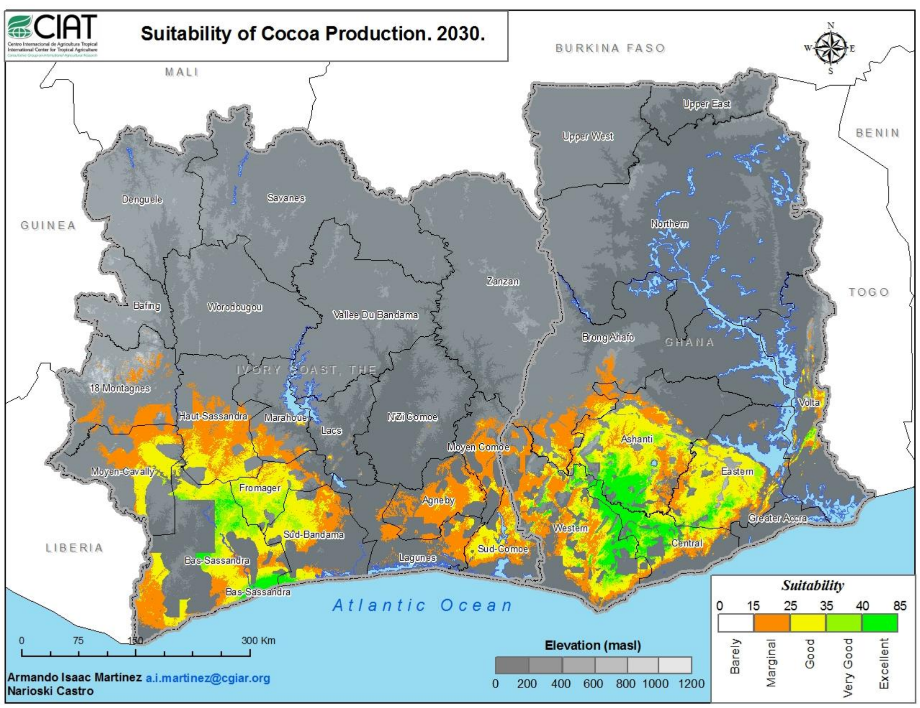

Figure 9: Climate suitability for cocoa production in 2050 according to 19 GCM using MAXENT crop prediction model.

By 2030, suitable areas start shifting, affecting mainly the southern area of Brong Ahafo, and Western regions in Ghana and Sud-Comoe, Agneby, Moyencomoe and Sud-Bandama regions in Côte d'Ivoire(Figure 8). According to these predictions, conditions similar to the current climates will remain only in the areas between Central, Ashanti and Eastern regions in Ghana and between Fromager and Bas-Sassandra regions in Côte d'Ivoire. The remaining areas will still be suitable to grow cocoa, although they will be less suitable than now.

By 2050, cocoa production will become concentrated in two areas in Ghana, between the Central and Ashanti regions, and in the mountain ranges of the Kwahu Plateau between the Eastern and Ashanti regions. In Côte d'Ivoire, the areas between Fromager and Bass-Sassandra will decrease in suitability but will retain enough suitability for growing cocoa. An increase of up to 2°C in mean annual temperature will cause a considerable decrease of suitability for cocoa growing-areas in both countries. The higher temperatures could intensify the dry season, to which cocoa is very susceptible (Anim-Kwapong and Frimpong, 2005) and higher within-season water deficits caused by higher evaporative demand due to higher temperatures.

The coefficient of variation (CV) between the GCMs for the bioclimatic variables in 2030 and 2050 overall ranged up to 25%. They were even lower for cocoa-growing areas and may therefore be accepted as reliable (Figure 10).

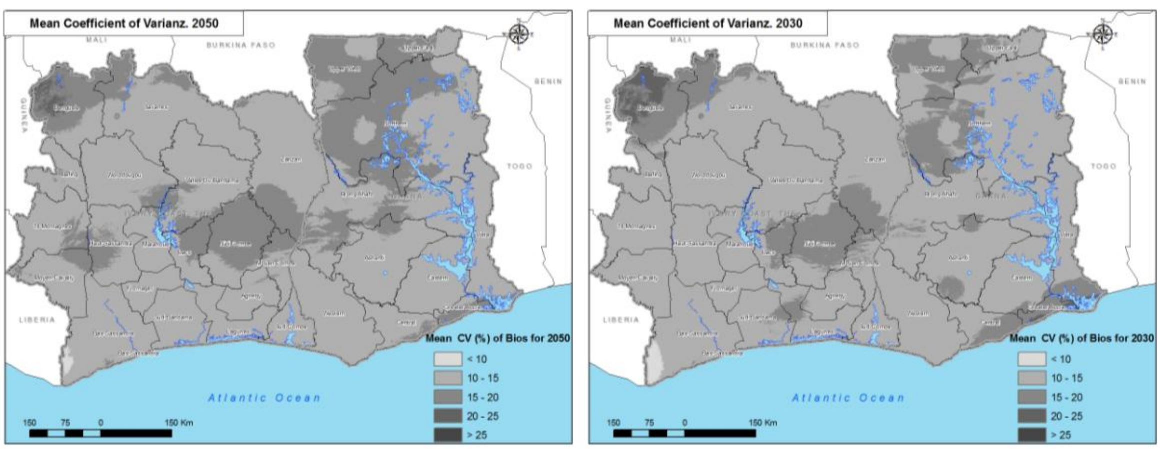

Figure 10: Mean coefficient of variance of bioclimatic variables for 2030 and 2050.

6.c Suitability change of cocoa growing areas

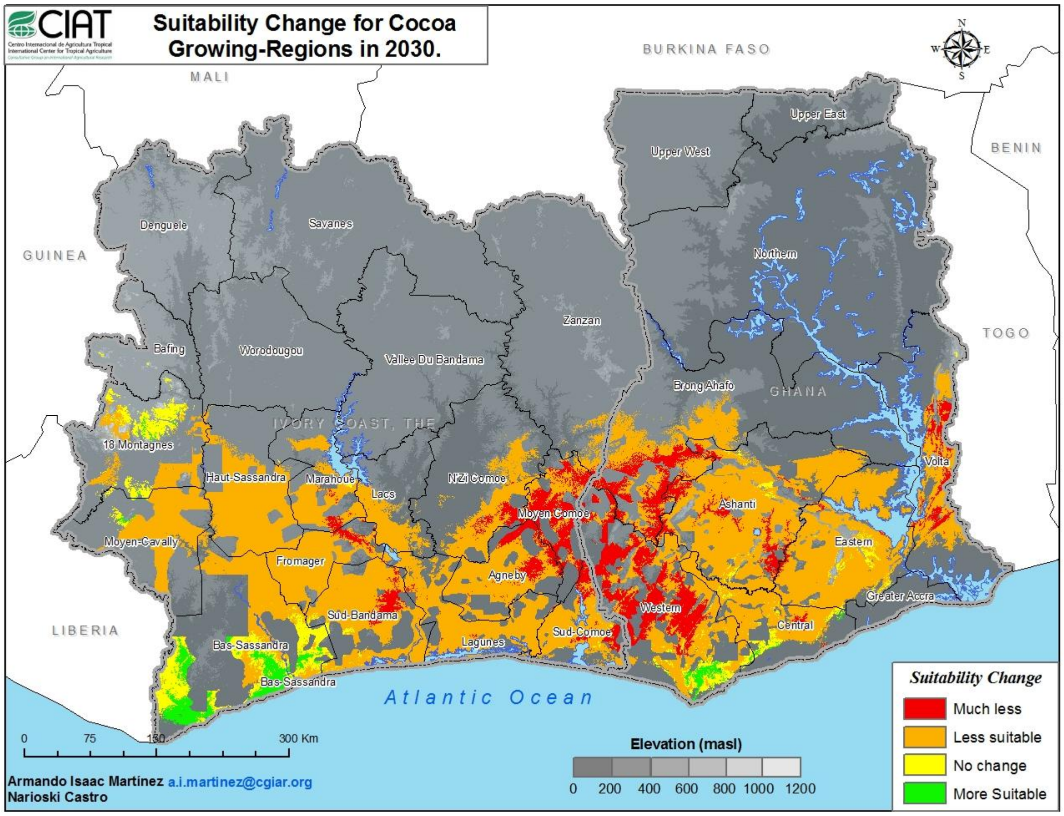

Figure 11: Suitability change for cocoa growing-regions by 2030.

By 2030, while most areas in both countries show a slight decrease in suitability for growing cocoa, some regions, such as Moyen Comoe, Western and south of Brong Ahafo in Ghana, show bigger decreases in suitability. Only a few areas, such as the Bas-Sassandra region and southern parts of Western region gain in suitability by 2050 (Figure 11). By 2050, suitability of cocoa growing areas will decrease drastically in Moyen-Comoe, Sud-Comoe and Agneby regions in Côte d'Ivoire, and in Ghana the most affected regions are Western and Brong Ahafo(Figure 12).

The areas that show the highest average loss of suitability lose 40–70% (in percentage points) from their current suitabilities of 60–80%. Areas around the mountain ranges of Kwahu Plateau between Eastern and Ashanti regions in Ghana, and 18 Montagnes in Côte d'Ivoire still remain highly suitable in 2050. While there will be a general shift to higher altitudes, the increase suitability due to increasing altitude is only about 10–30 percentage points. For a given location in the cocoa-growing areas, the degree of agreement between all GCMs in predicting changes in the same direction as the average of all models is 80–100% in cocoa growing areas (Figure 13).

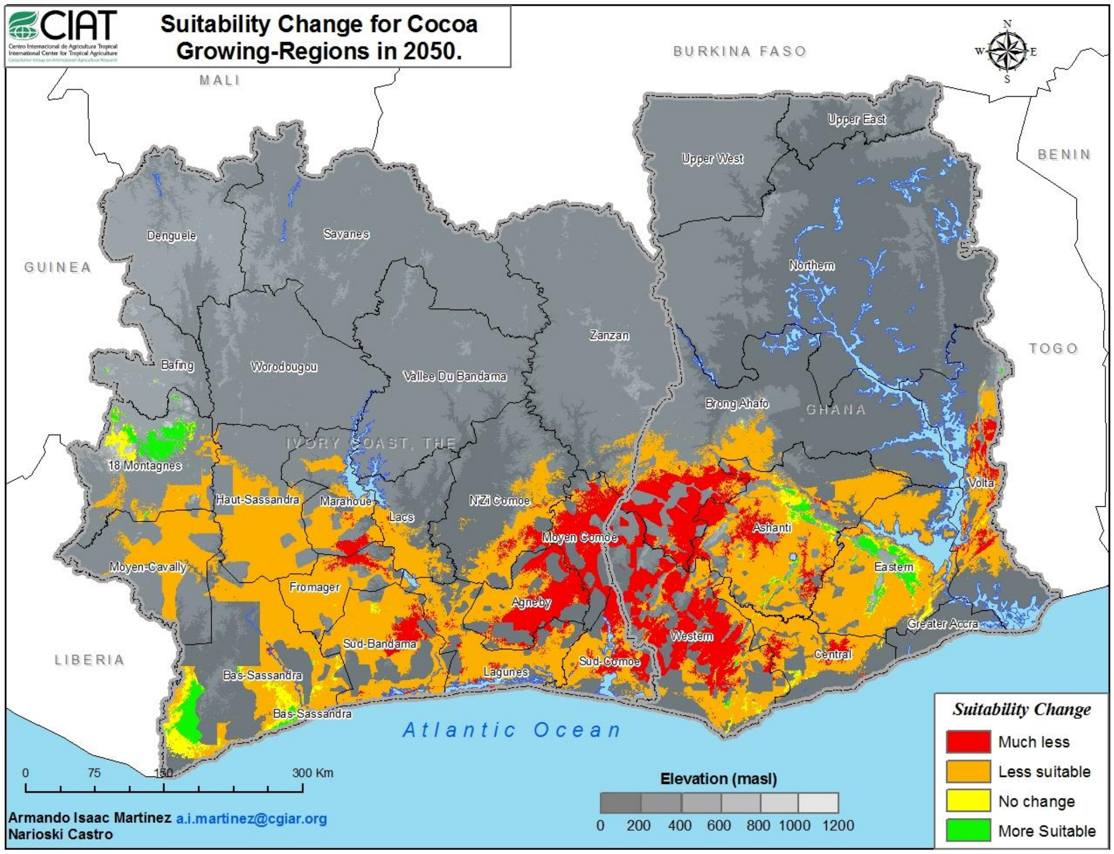

Figure 12: Suitability change for cocoa-growing regions by 2050.

According to MAXENT, it is predicted to decrease the suitability by 2050 on most of all growing areas.

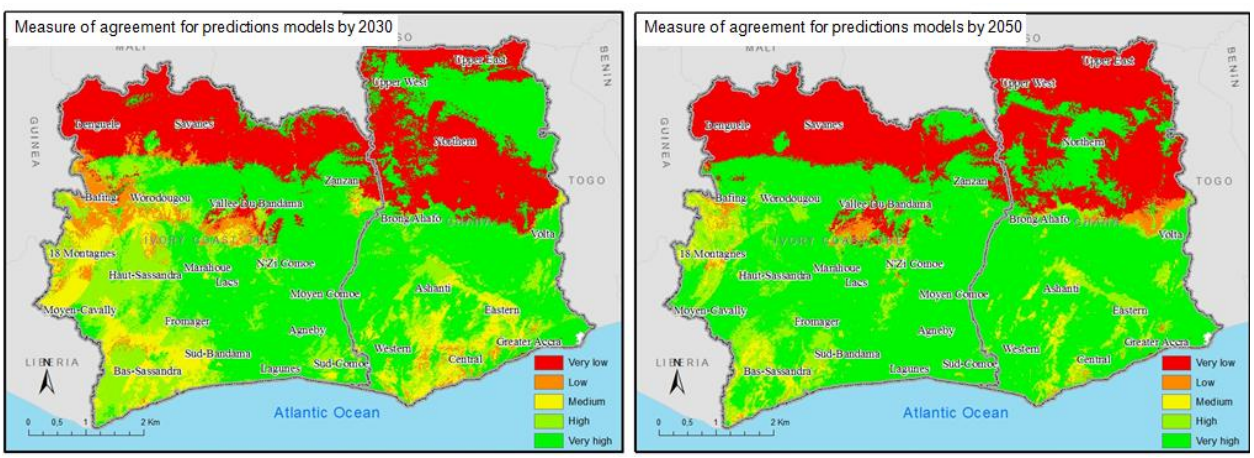

Figure 13: Measure of agreement of models predicting changes in the same direction as the average of all models at a given location for 2030 and 2050.

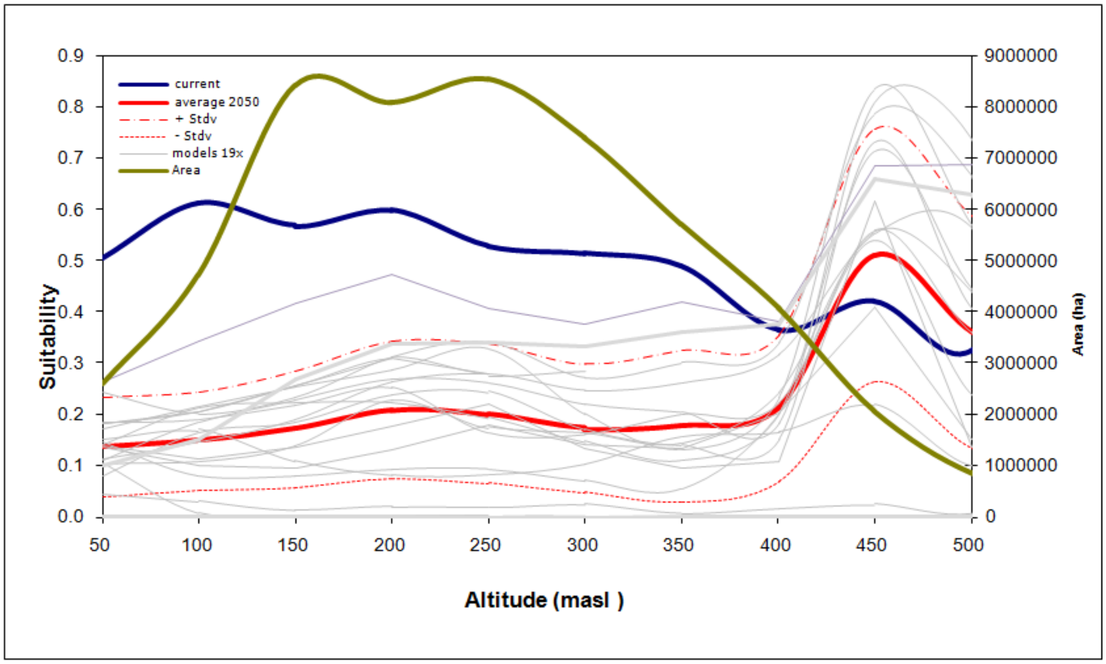

Figure 14: The relation cocoa suitability and altitude today (blue line) and in 2050 (red line) in Ghana and Côte d'Ivoire. Grey lines indicate projections of different GCMs. Green line indicate land availability in different altitudes.

With progressive climate change, cocoa will lose suitability in lowland areas and gain in the highlands (Figure 14). We did not use altitude as a variable in the suitability modeling, so it is therefore independent of the other variables. Altitude is, however, strongly correlated with temperature-related variables. The altitude of the optimum cocoa-growing areas is currently 100–250 masl, but by 2050 will increase to 450–500 masl. Compared to today, by 2050 areas at altitudes between 100–300 masl will suffer the greatest decrease in suitability and areas around 450 masl will experience the highest increase in suitability (Figure 8). Areas at higher altitude are limited (green line Figure 14), which is another reason why the suitable area decreases very drastically.

7 Result III: Environmental factors which drive cocoa suitability

The step-wise-regression analysis identified primarily the bioclimatic variables related to temperature increase as drivers of the predicted shifts in suitability. The step-wise regression analysis for changes in suitability on observed sample points for 2050 identified temperature of the warmest month as the main driving factor, explaining 25.3% of the variability for negative change in suitability (Table 2). The mean temperature of the warmest month will increase of up to 2.4 °C by 2050.Also temperature seasonality is identified as a main driving factor for negative suitability change (Table 2).

Table2: Contribution of different bioclimatic variables to the predicted shift in suitability for cocoa in Ghana and Côte d'Ivoire, between current and 2050 conditions, in locations with decreasing suitability.

Variable	Adjusted R^2	R^2 due to variable	% of total variability	Present mean	Change by 2050s
Locations with decreasing suitability (n=288, 98 % of all observations)					
Bio 5 - Maximum temperature of warmest month (°C)	0.258	0.104	25.3	33.0	+ 2.4
Bio 7 - Temperature Annual Range (Bio5 – Bi06) (°C)	0.097	0.091	23.6	12.5	+ 0.7
Bio 1 - Annual mean temperature (°C)	0.321	0.063	15.2	26.2	+ 2.0
Bio 15 - Precipitation Seasonality (Coefficient of Variation)	0.154	0.057	13.8	55	+ 1.9
Bio 19 - Precipitation of Coldest Quarter (mm)	0.345	0.029	7.1	369	- 17.5
Bio 4 - Temperature seasonality (standard deviation *100)	0.380	0.021	5.0	1021	+ 26.5
Others*			10.1		

*Variables explaining less than 4% of total variability are not listed.

8 Conclusions and Recommendations

8.a Conclusions

- In the cocoa-growing regions in Ghana and Ivory Coast, the yearly and monthly minimum and maximum temperatures will increase by 2030 and will continue to increase progressively by 2050 (up to 2.0°C). Changes in yearly and monthly precipitation will be trivial.
- The implications are that the suitability within the current cocoa-growing areas will decrease seriously by 2050.
- Climate suitability for cocoa will decrease seriously in Agneby, Lagunes, Moyen-Comoe and Sud Comoe regions in Côte d'Ivoire and also in the west side of Western region in Ghana.
- Areas around mountain ranges in Ghana (Kwahu Plateu, between Eastern and Ashanti regions) and Côte d'Ivoire (18 Montagnes) will still remain climatically highly suitable in 2050
- The increase of the maximum temperature of the warmest month and annual temperature range will negatively impact cocoa-growing regions by 2050. These changes in temperature will also increase evapotranspiration of cocoa trees.
- The optimum cocoa-growing area is currently at an altitude between 100 and 250 masl, which will increase by 2050 to an altitude between 450 and 500 masl.
- Climate change will also increase the pressure on forest areas and on other important habitats for fauna and flora.

8.b Recommendations

The development and implementation of adaptation strategies to face progressive climate change depend on the participation of all actors in the cocoa sector. The recommendations below are specific to each of them.

For farmers:

- To implement new technologies available mainly for drought-tolerant germplasm and irrigation systems;
- To implement an efficient cocoa shade management (Isaac et al., 2007), that can contribute to buffering temperatures;
- As the current growing areas become hotter, farmers should implement activities to prevent bushfires; and
- Farm diversification with alternative crops such as orange, oil palm and cashew (Anim-Kwapong and Frimpong, 2005) for areas that will become unsuitable in the future.

For researchers:

- Research on drought-tolerant cocoa germplasm and irrigation systems;
- Further research on the effects of climate change on crops including the implementation of technological alternatives to explore better environmental and economic options;
- Participate in the development of nationals policies for adaptation;

- Evaluate the implications of changes in cocoa quality and quantity on the social measure of income, livelihoods, poverty and equity; and
- Identify alternative crops for areas where cocoa will become unsuitable.

For governments:

- Encourage the production of cocoa through access to credit for cocoa farmers;
- Promote access to alternative agricultural practices and technologies through agricultural extension programs;
- Implement the awareness of climate change, by promoting and publishing research projects on climate change through campaigns of public information through the national communications to the UNFCCC; and
- Support research and development on appropriate technologies to help farmers adapt to climate change.

9 Climate change impact on three major cash crops in Ghana and Côte d'Ivoire

The aim of the study it is to "Predict the Impact of Climate Change on Cocoa, Cashew, and Cotton-Growing Regions in Ghana and Cote d'Ivoire". There are separate reports for each crop; this one focuses on cashews.

To provide a complete picture of both countries for the predictions of climate change on these major cash crops, we present the combined results for all three. We used the same methodology for all of three crops, as described in the methodology section above.

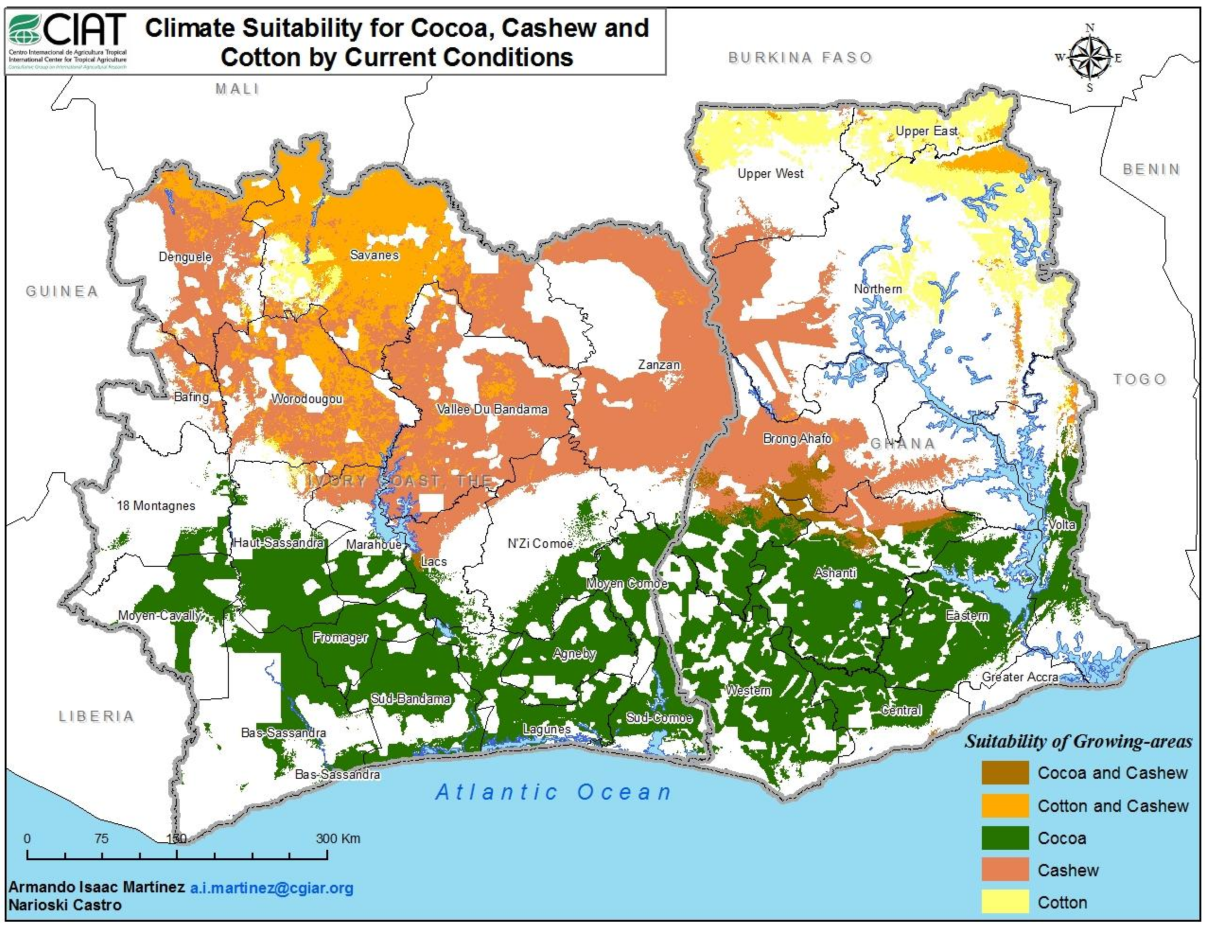

Figure 15: Current climate suitability for cocoa, cashew and cotton production in Ghana and Côte d'Ivoire. The climate suitability predictions do not include the protected areas, forest, urban and water bodies.

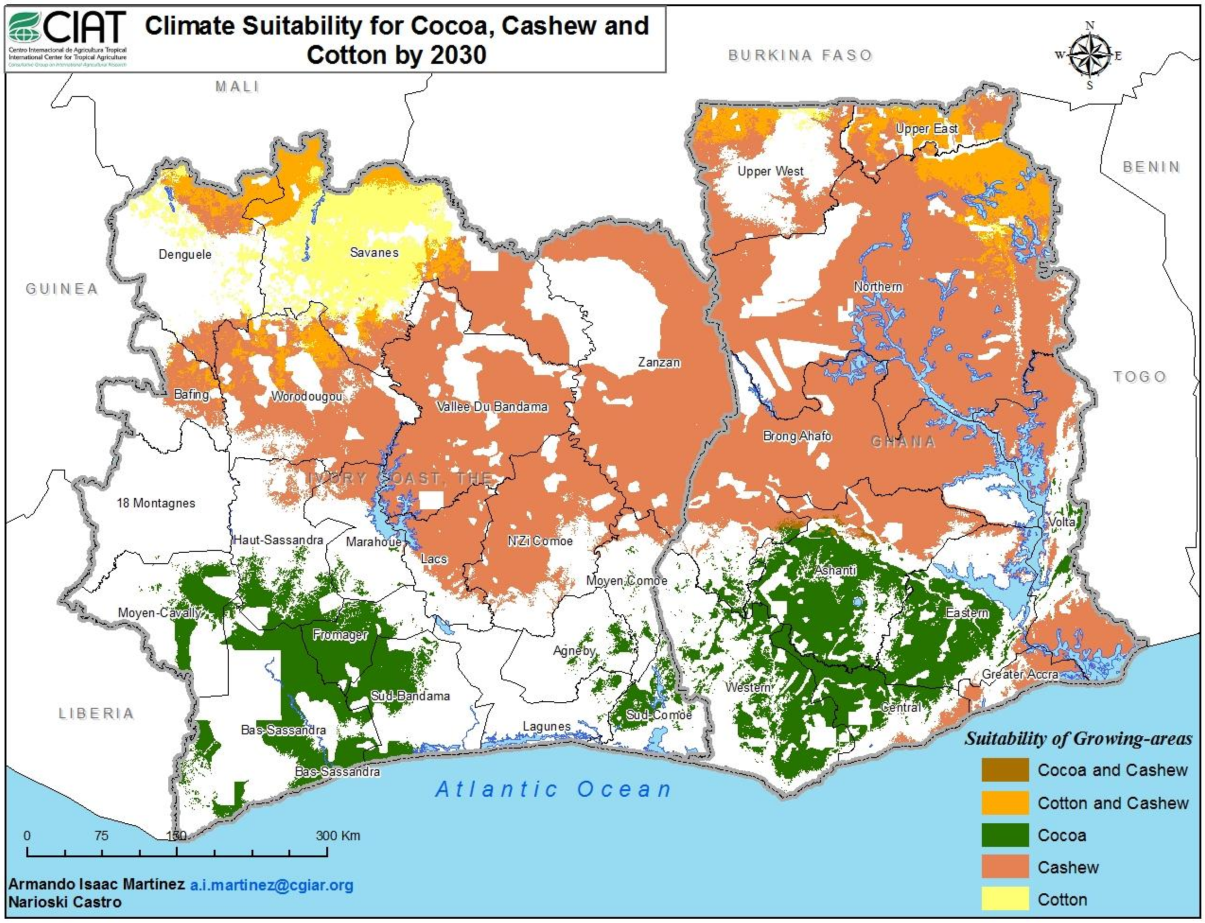

Figure 16: Climate suitability by 2030 for cocoa, cashew and cotton in Ghana and Côte d'Ivoire. The climate suitability predictions do not include the protected areas, forest, urban and water bodies.

According to MAXENT cocoa growing-areas lose considerable suitability in Lagunes, Agneby, Moyen-comoe and Sud-comoe regions in Côte d'Ivoire by 2030. The climate conditions become more favorable for cashew in the savanna areas. There is a small reduction of the area predicted as suitable for cotton in both countries although there is no change from current distribution in the northern regions of Ghana and Côte d'Ivoire.

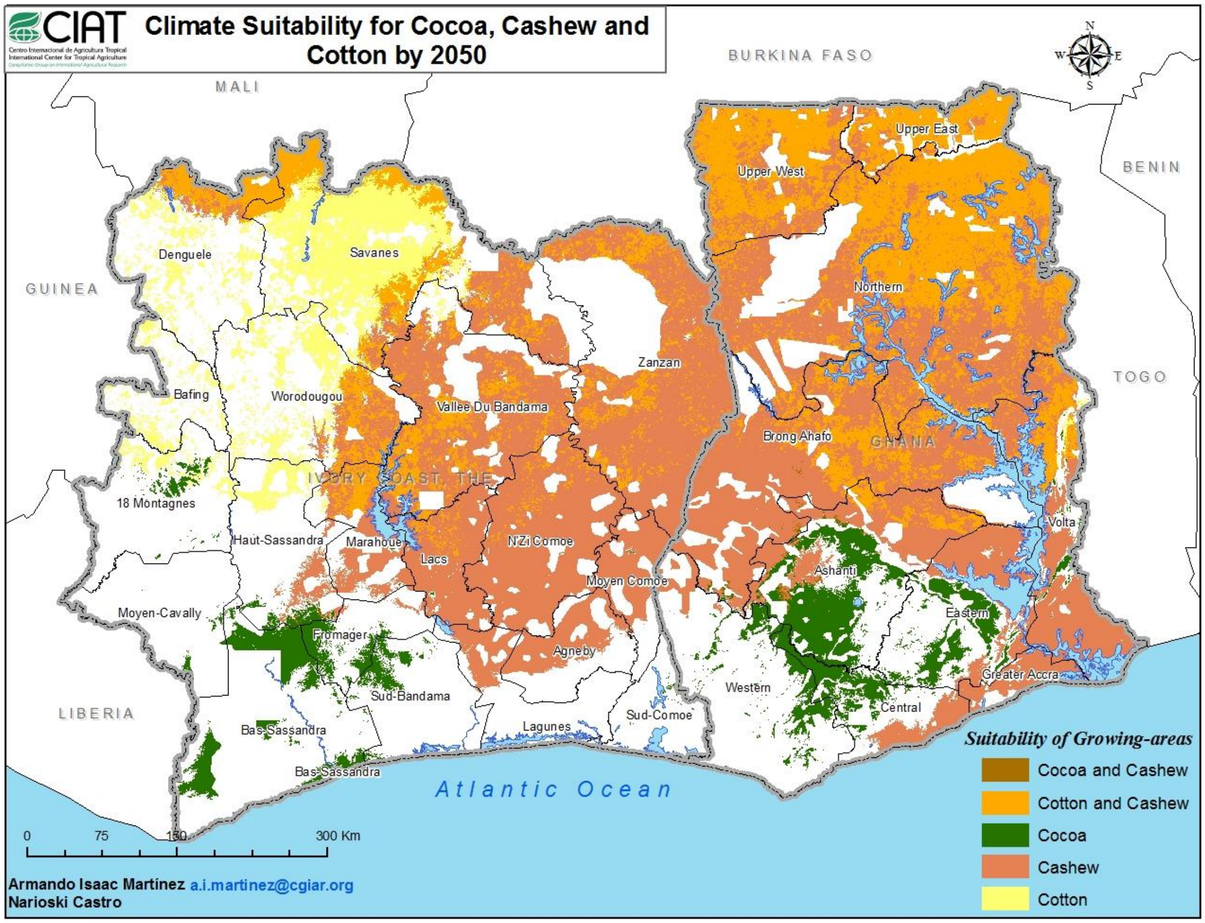

Figure 17: Climate suitability by 2050 for cocoa, cashew and cotton in Ghana and Côte d'Ivoire.The climate suitability predictions do not include the protected areas, forest, urban and water bodies.

Cocoa continues to lose suitable area by 2050 as the temperature increases. Cashew is affected positively under predicted climates of 2050 and gains considerable suitable area. Cotton-growing areas become somewhat less suitable by 2050 but overall remain satisfactory.

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11 Annex I: Consultations via email and during cocoa summit for model validation

1.- What country and district are you from?

2.- Do you agree with the prediction of the current suitability in the growing areas for each category in the districts?

Marginal:

Suitable:

Very Suitable:

Excellent:

3.- According to your knowledge and experience, is there any area missing?

3.1.- If so, would you consider these missing areas environmentally similar to other areas included in the results? Which ones would be these areas? (from the results).

4.- Do you have any other comments?

12 Annex II: Summarized responses for model validation

Table3.Summarized responses on current cocoa distribution results conduced using MAXENT.

No.	Questionnaire	1	2	3	4	5	6
	Product	Cocoa	Cocoa	Cocoa	Cocoa	Cocoa	Cocoa
1	Country/ District	Ghana	Amansie Central-Ghana	Ghana Ketu District		USA Gellyberg PA	
2	Agree with the prediction of current suitability?	Marginal	Very suitable	Suitable	Marginal	Suitable	Very marginal
3	Any missing area	Yes, but it has already been indicated on map (some places in the Jomoro District of the Western Region) Nkwanta and Tikobo areas	No	N/A	a.Soil type b.Bia selection of meteorological areas c.Topography d.Vegetation	SW RU &SW Ghana (Tarkwa) Tabou (along coast)	View climate, geomorphotogy &vegetation, possible National and intermetent intervention
3.1	is missing area similar to other areas		N/A	N/A	Yes	Yes although a bit wetter in these areas	No

4	Any comments	N/A	N/A	STCP baseline data on yields n=4335 (2001/2001) HH-2300 OBSERVATIONS	Further consultation required with key stakeholders involved in climate and environmental issues, land use and soil professional as well as qualitative information from farmers

13 Annex III: List of summit participants and model validation

Table 4. Contact list of participants of the cocoa summit held at COCOBOD in Accra, Ghana on April 6, 2011.

Name	Organization
Isaac Manu	Ghana Cocoa Board
P. Ntim	Ghana Cocoa Board
Jeph Mensah	IITA/STCP
Ambrose Dziwornu	IITA/STCP
Joseph Odamtten	World Cocoa Foundation
David Kpelle	Africa Cocoa Coalition, Accra
Susann Hofs	GIZ-MOAP
Emml Opoku	Ghana Cocoa Board
Bezt de Wilde	Netherlands embassy
Susanne Bouma	Netherlands embassy
Ernestine Doku-Marfo	Conservation Alliance-Ghana
Rebecca Asare	Katoomba Incubator NCRC
Jim Gockowski	IITA
G. Oduro Baah	COCOBOD
Organizers	
Peter Läderach	CIAT
Christian Mensah	AE-LBI
Eric Doe	AE-LBI

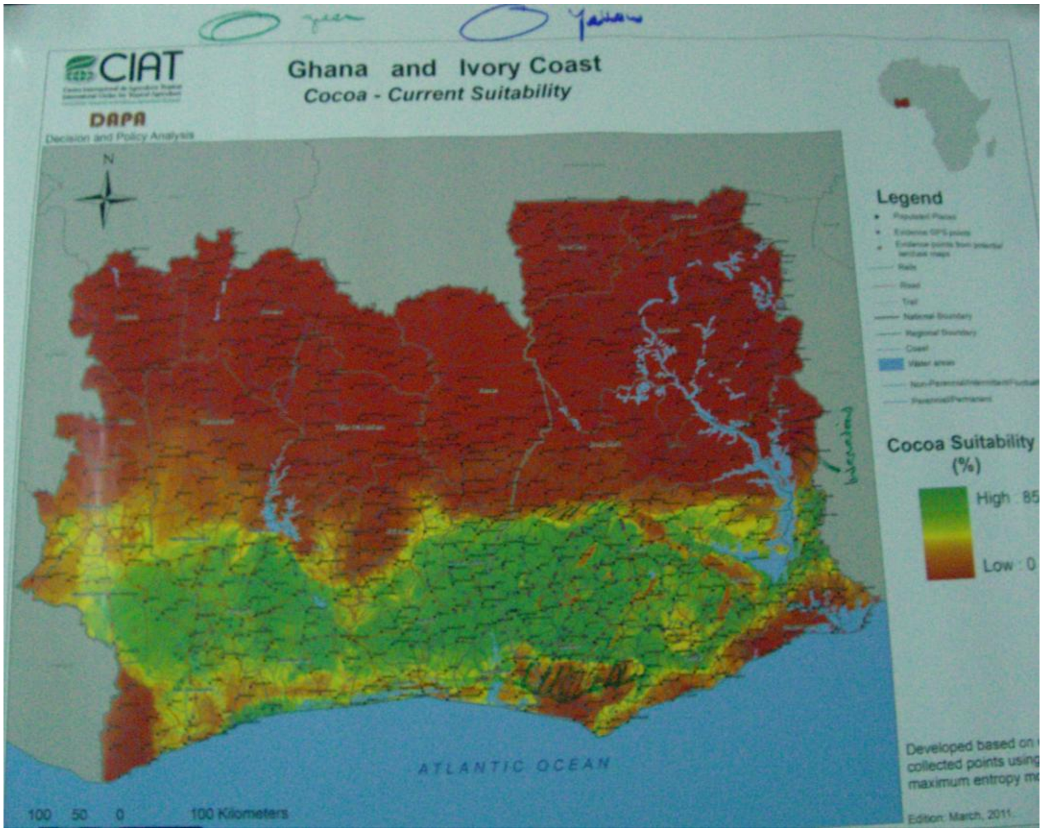

Figure 18: Climate Experts validated model by indicating performance of predictions during Cocoa summit at COCOBOD in Accra, Ghana on April 6th2011.