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

Final report
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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	A 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 of Anton Eitzinger, Armando Martinez and Narioski Castro. The compilation of the ground data has been facilitated through Agro Eco - Louis Bolk Institute in Ghana.

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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 cashew but summarizes the impact of climate change on all three crops in chapter 9. It aims to inform the cashew sector in particular, but all supply chain actors in the other sectors as well.

The objective of the research is to present future climate scenarios and to predict the impact of climate change on suitability to grow cashew in 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 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, provided by partners in Ghana and Côte d'Ivoire and from the literature.

The analysis focused on the specific regions where cashew is currently-grown. The study uses predictions of the future climates to predict the suitability of current cashew-growing areas to continue growing them by 2030 and 2050.

The current optimum altitude for cashews in both countries is 300 – 500 meters above sea level (masl), which will decrease to 100 – 350 masl by 2050. Increasing minimum temperature of coldest month explains the gain in climate suitability for cashews in Ghana and Cote d'Ivoire.

The influence of climate change on the suitability of an area for cashews is site-specific. There are areas that will become unsuitable for cashews and where farmers will need to seek alternative crops. These are the Savanes, Denguele and Worodougou regions in Côte d'Ivoire and in the Techiman municipality, located between Sawla-Tuna-Kalba and Bole districts in Ghana. In contrast, there are areas where suitability for cashew will increase, mainly in the Agneby, N´zi comoe, Moyen comoe and Lacs regions in Côte d'Ivoire and in the Upper East, Upper West, and Northern regions, most of the Brong Ahafo districts and some coastal districts in Ghana. We did not consider protected areas, such as forest reserves, as alternative sites for cashews to discourage invasion and forest clearing to establish new cashew areas.

Climate change brings not only bad news but also a lot of increased potential. Cashew production is a good example of the suitable area expanding under the new climatic conditions.

3 Project Background and Objectives

Cashews, which are well suited to the natural conditions of Côte d’Ivoire and Ghana, are an important cash crop in both countries. In 2008, Côte d’Ivoireproduced308,700 tons compared with34,000 tons in Ghana (FAO, 2008). Global demand is growing and the crop has the potential to reduce poverty among the rural poor of both countries.

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 cashews, with the primary aim of informing the cashew sector but with implications for the actors in other supply chains. All three papers are summarized in Chapter 9.

The paper includes climate predictions, predictions of crop-climate suitability, and detailed analyses for the cashew-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 cashews;

To predict the change in climate for the cashew-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 cashews.

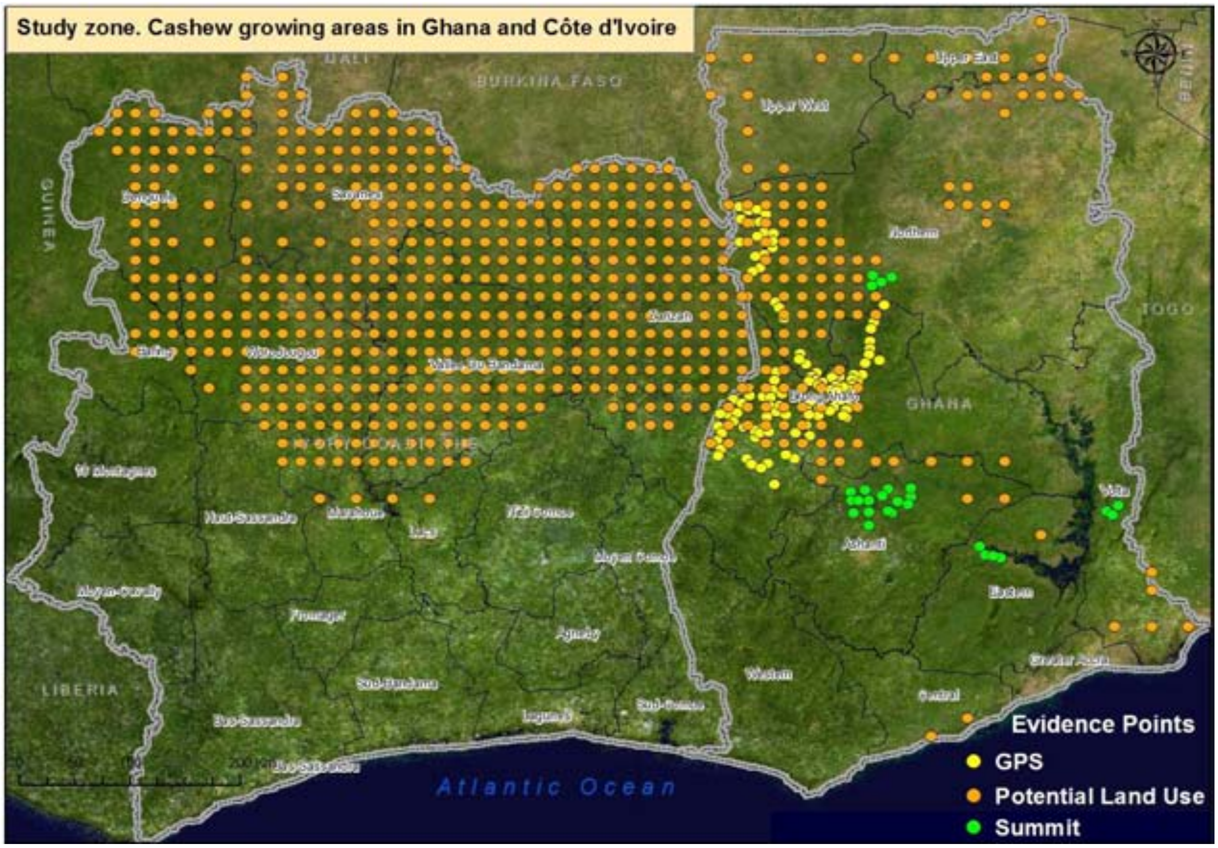

Figure 1: Ghana and Côte d'Ivoire cashew growing areas.

Data collected using GPS (yellow dots),land-use data (orange dots) and data provided by partners during the summit (green dots).

4 Methodology

4.a Current climate

For the current climate (baseline) we used historical climate data from thewww.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 a 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 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 method for this sort of analysis (Elith et al., 2006).

Data collection and model calibration

For the predictions we needed evidence data of current distribution of cashew production. We compiled the evidence data from 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 cashews in both countries. For some areas the collected data were insufficient to determine the spatial distribution of the growing areas and we used land cover, maps of potential for cashew (Dedzoe, 2001) and general soil maps (Dabin et al., 1960) to identify current cashew-growing areas.

One hundred and twelve points were collected during a field mission using GPS(all in Ghana). For Côte d'Ivoire it was impossible to collect evidence data because of the civil war at the time. We identified 649 points through potential land use, using overlapping layers of land cover and potential land use and the opinions of experts in the area. We used a total of761 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 expert opinions and reran MAXENT. We presented the results to a cashew summit representing the cashew sector and its supply chain in Accra, Ghana on 7 April, 2011. We incorporated participants´ feedback and reran MAXENT for the final analysis.

Suitability ranges

Climate suitability is the level of certain climatic characteristics that determine which areas have the potential to grow a crop successfully. For the cashew 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 cashews (Table 1).

Table1: Categories used for the map.

Maxent Ranges	Category	Color in map
0 – 0.25	Barely	No color
0.25 – 0.40	Marginal	Orange
0.40 – 0.60	Good	Yellow
0.60 – 0.80	Very Good	Light green
0.80 – 0.92	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 areas and water bodies as well as forested and protected areas as not available for cashews, 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 data from 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 cashew growing areas

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

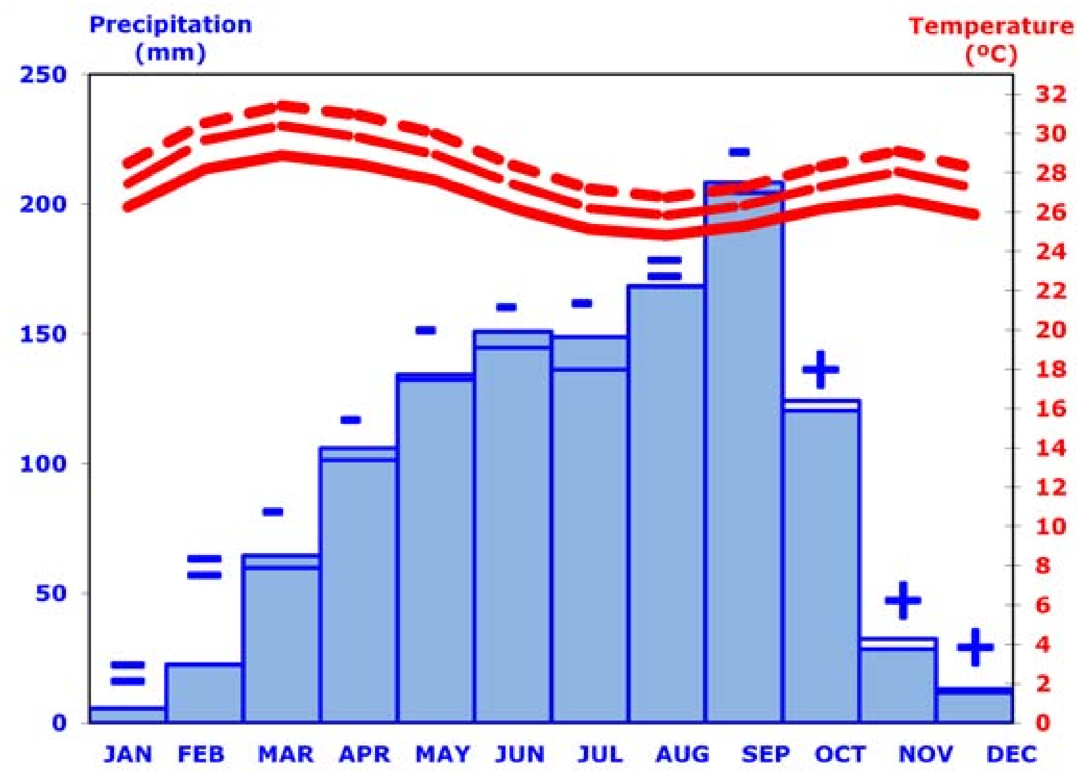

Figure 2: Climate trend summary for 2030 and 2050 for sample sites.

We used 761 evidence points in the analysis. Blue bars show current and 2050 precipitation trends and red lines show the current, 2030 and 2050 temperature.

- Temperatures increase and the average increase is 2.3°C passing through 1.3°C in 2030;
- The mean daily temperature range decreases from 11.2°C to 10.6°C in 2050;
- Rainfall decreases from 1168 millimeters to 1147 millimeters by 2050 passing through 1164 in 2030. The variations are trivial and therefore not significant for the crop development (Figure 3); and
- The maximum number of cumulative dry months is constant at5 months.

Extreme conditions

- The mean monthly maximum temperature increases from 35.4 °C to 38.1 °C while the warmest quarter is 2.6 °C hotter by 2050;
- The mean monthly minimum temperature increases from 18.8 °C to 20.9 °C while the coldest quarter gets hotter by 1.8 °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; the seasonality of precipitation is unchanged.

Variability between models

- The coefficient of variation of temperature predictions between models is 3.8%;
- Temperature predictions were uniform between models with no outliers;
- The coefficient of variation of precipitation predictions between models is 8.1%; and
- Precipitation predictions were uniform between models with no outliers.

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

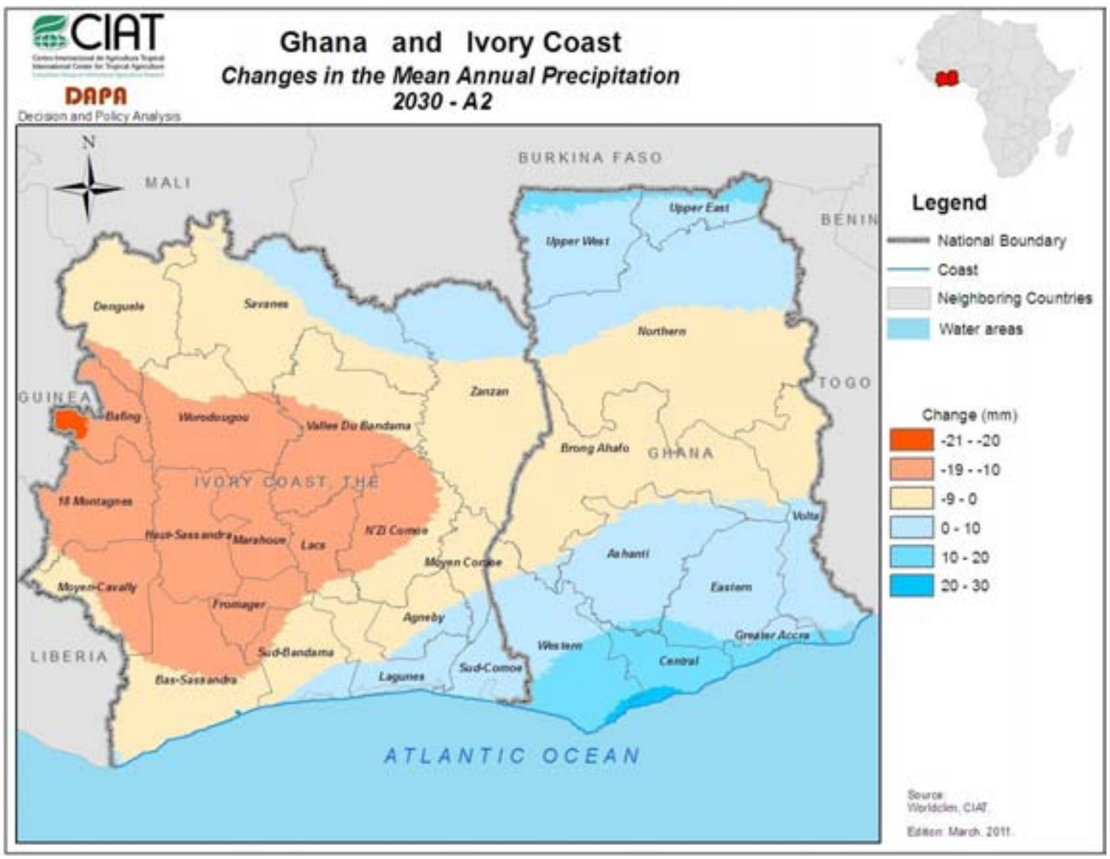

Figure 3: Mean annual precipitation changes by 2030 according to nineteen GCM models (SRES A2) for Ghana and Côte d'Ivoire.

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

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

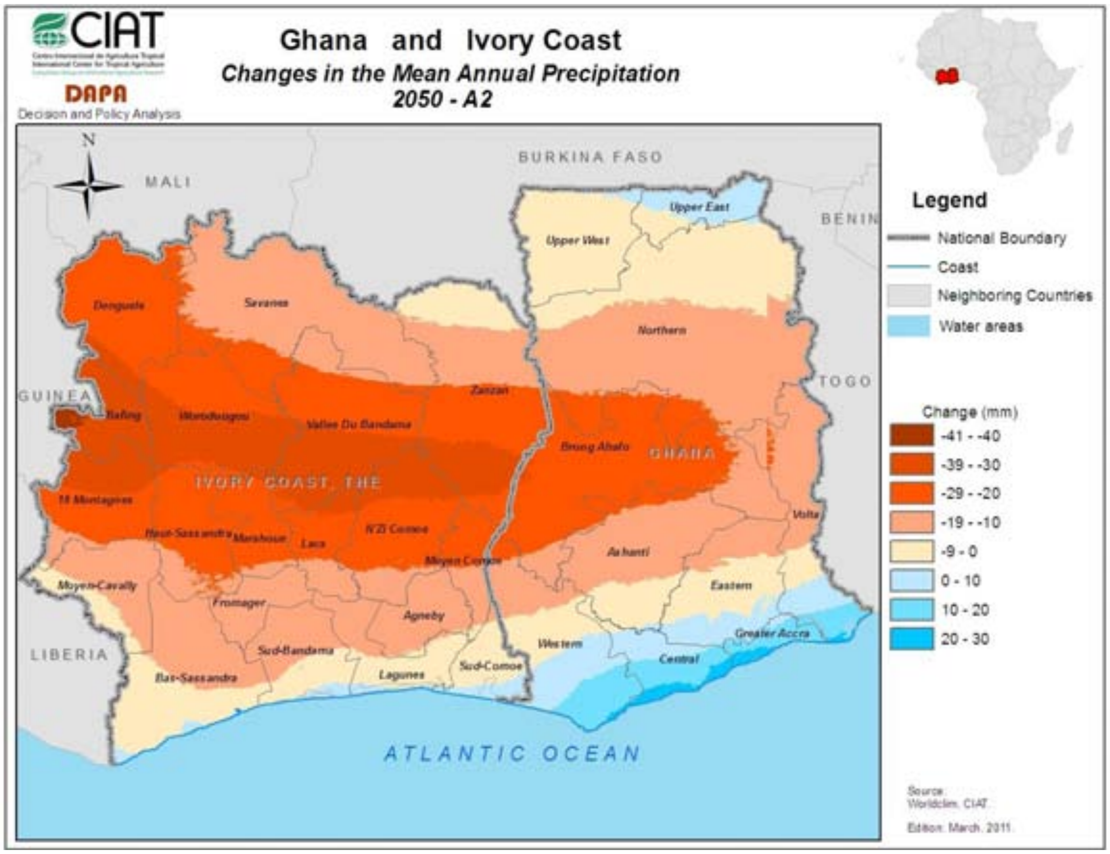

Figure 4: Mean annual precipitation changes by 2050according to nineteen GCM models (SRES A2)for Ghana and Côte d'Ivoire.

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

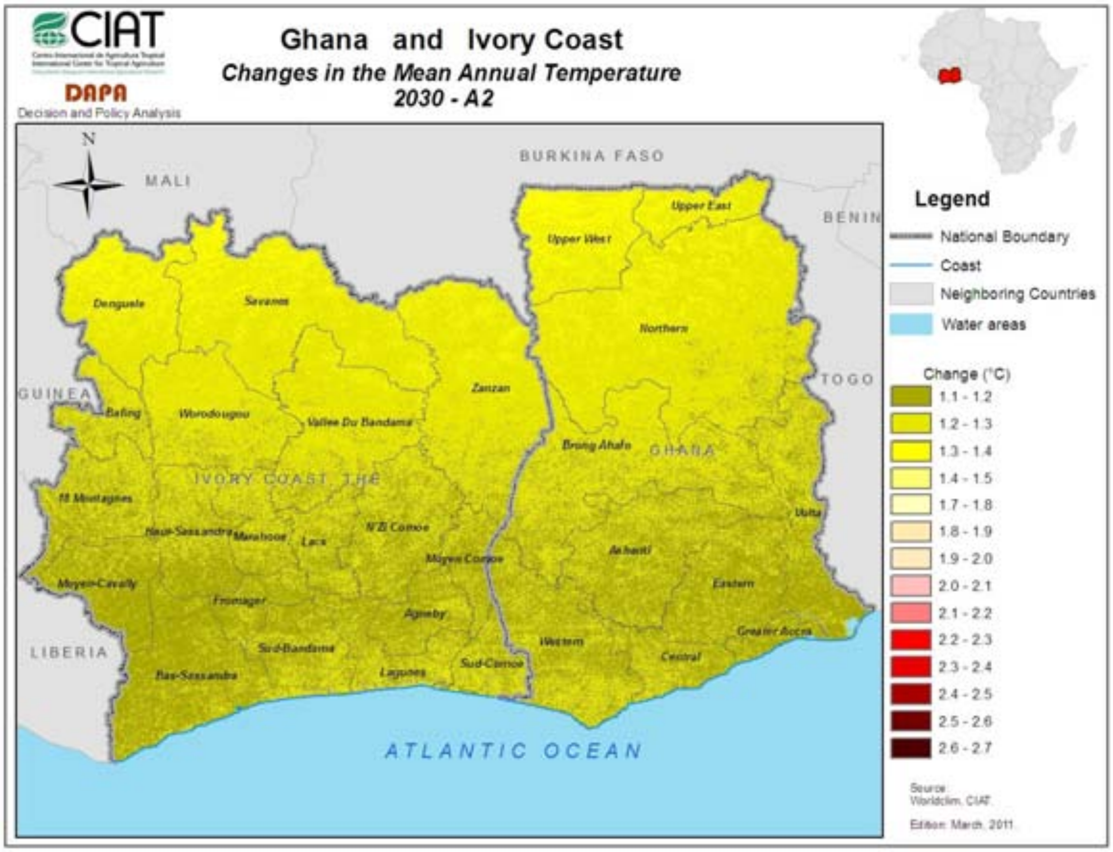

Figure 5:Mean annual temperature changes by 2030according nineteen GCM models (SRES A2)for Ghana and Côte d'Ivoire.

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

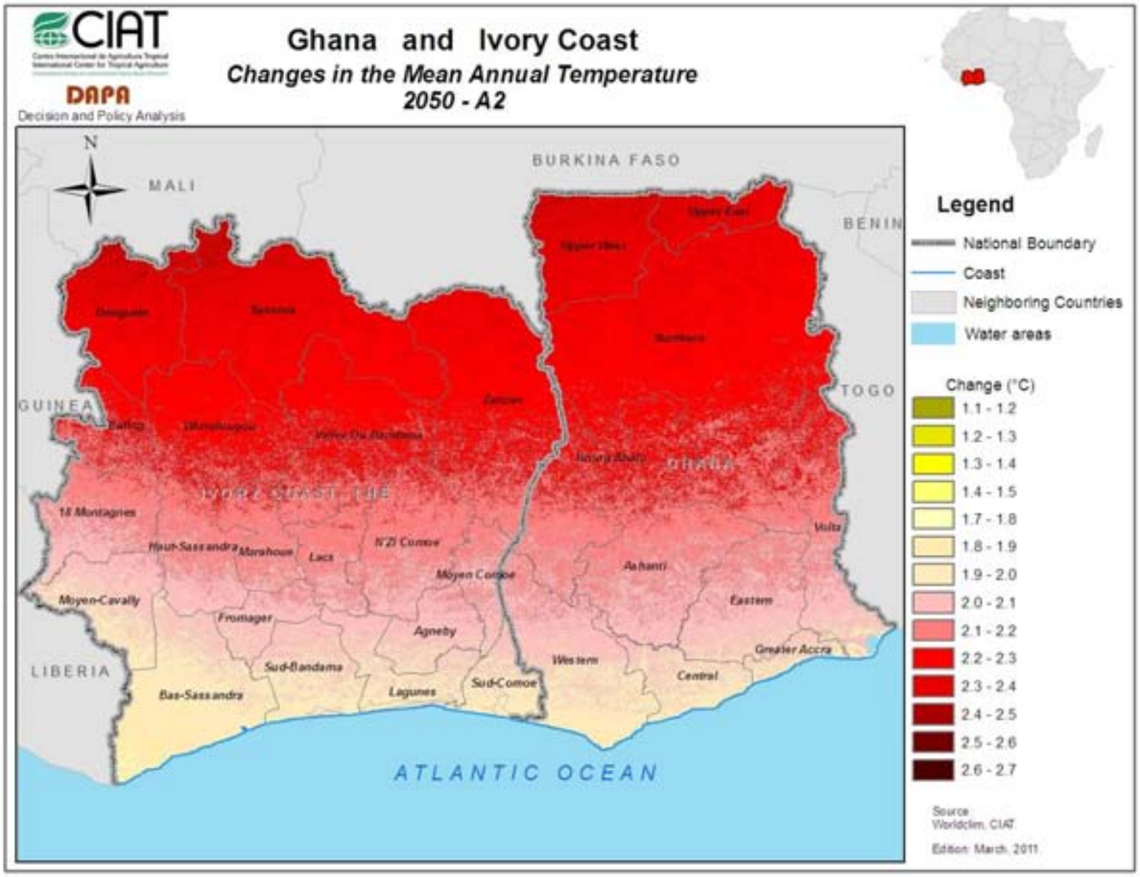

Figure 6:Mean annual temperature changes by 2050 according to nineteen GCM models (SRES A2) for Ghana and Côte d'Ivoire.

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 cashew growing areas

In Ghana and Côte d'Ivoire the yearly and monthly minimum and maximum temperatures will increase by 2030 and continue to increase by 2050. Overall climates become more seasonal in terms of variability through the year with temperatures in specific districts increasing by about 1.3 °C by 2030 and 2.3°C by 2050.Seasonality in precipitation remains unchanged, and the number of dry months is also unchanged at 5 months. The implications are that the distribution of suitability for most of the current cashew-growing areas in Ghana and Côte d'Ivoire will increase by 2050.

The 77.6% of observed locations with increasing suitability by 2050 are driven by changes of mean temperature of warmest quarter (Bio10) with an average of 2.6 °C (see chapter 7).

6.a Current suitability of cashew growing areas

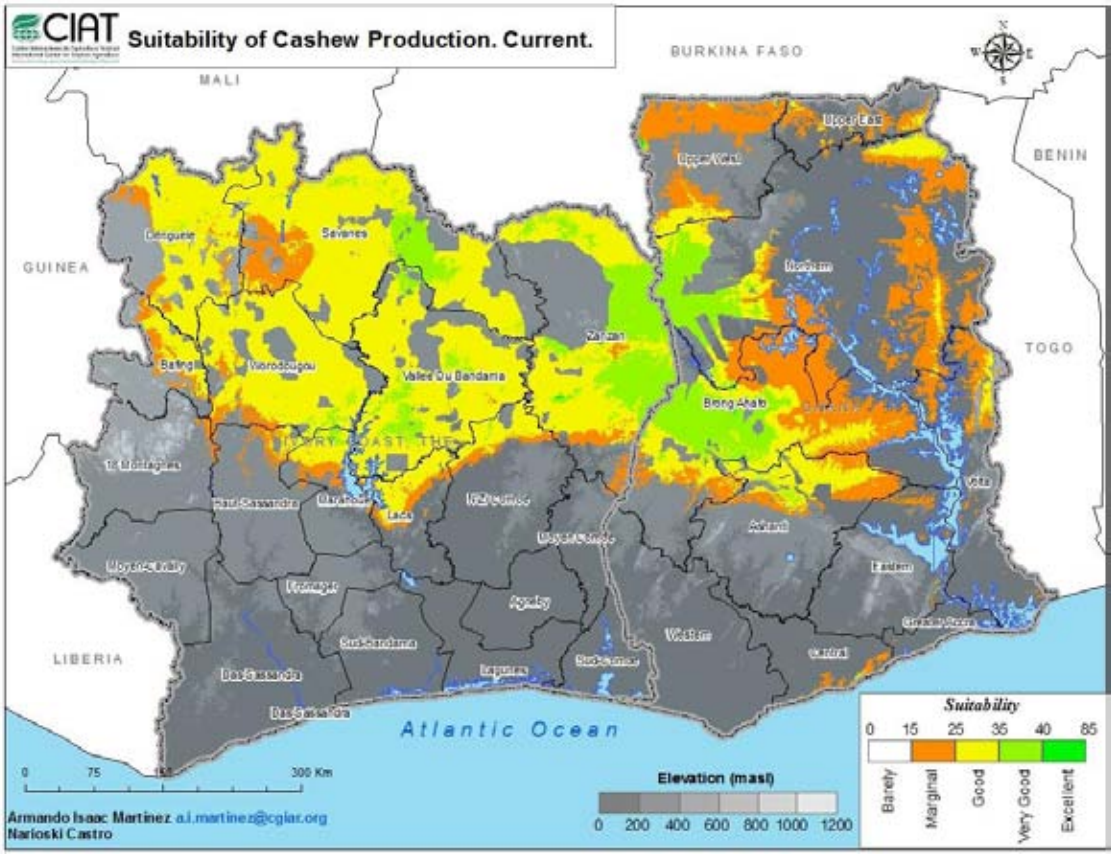

Figure 7: Current climate suitability for cashew production within cashew-growing regions of Ghana and Côte d'Ivoire.

The grey areas inside the suitable areas are protected areas not available for cashew production.

Currently, the main cashew-growing areas in both countries are located in the Guinea and Sudan savannah eco-zones. In Ghana, they are mainly in the Northern and Brong Ahafo regions and in Côte d'Ivoire these zones are mainly in the Zanzan, Valle du Bandama, Savanes, Worodougou and Dengueleregions (Figure 7).

6.b Future suitability of cashew growing areas

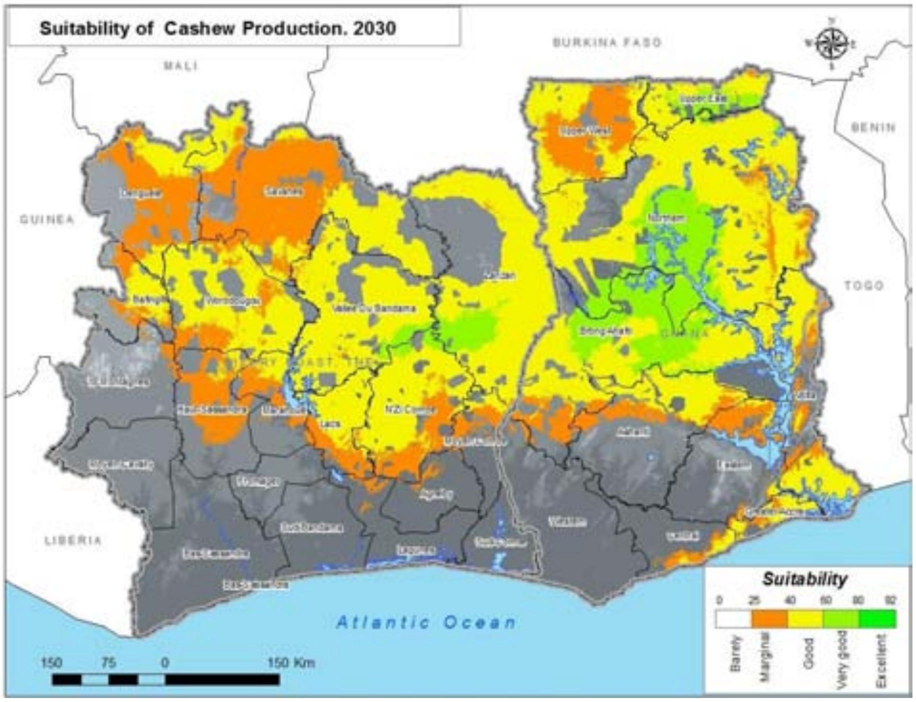

Figure 8: Climate suitability for cashew production in 2030 according to 19 GCM using MAXENT crop prediction model.

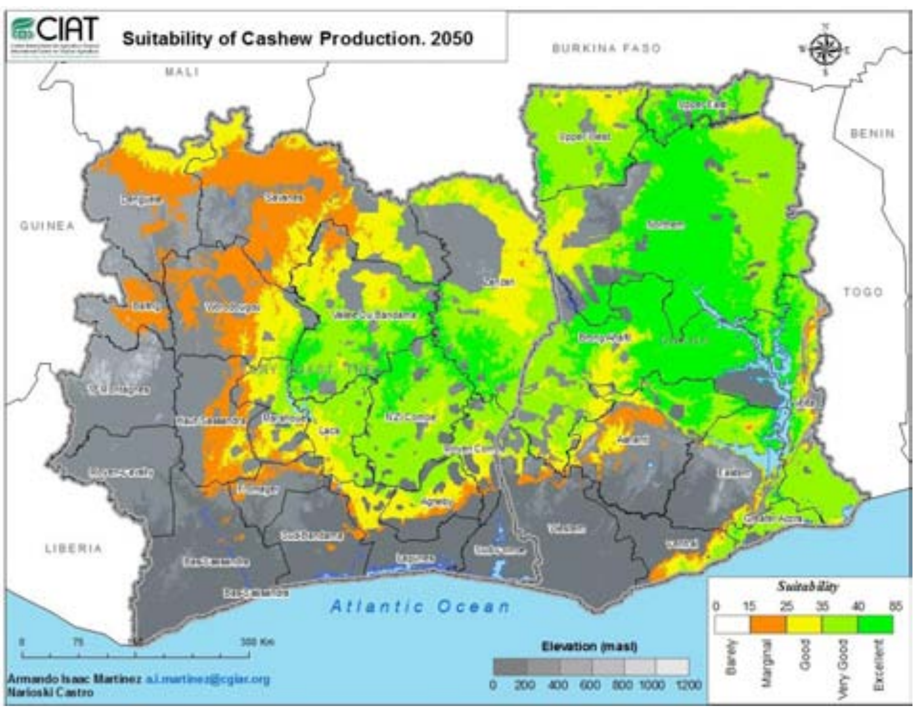

Figure 9: Climate suitability for cashew production in 2050 according to 19 GCM using MAXENT crop prediction model.

By 2030,N´zicomoe, Greater Accra, Volta (south side) and the Northern area in general will have an increase in suitability, while only the Kintampo North, Pru and Central Gonja districts in Ghana and the Bondoukou-Sandegue district of Côte d'Ivoire will have similar suitability to now. There will be a slight decrease of suitability in the Sawla-Tuna-Kalba, Bole, Tain, Wenchi, Jaman Norh and Jaman South districts in Ghana, and the Boundiali, Korhogo and Odiene districts of Côte d'Ivoire(Figure 8). The remaining areas will be less suitable but in general will still good enough to grow cashew.

By 2050,most of the cashew-growing areas will become more suitable, mainly in the Northern, Brong Ahafo and Upper East regions of Ghana.

The coefficient of variance (CV) between GCMs for the 2030 and 2050 bioclimatic variables range between 0 and 25%. They are generally lower for cashew-growing areas and may therefore be accepted as reliable (Figure 10).

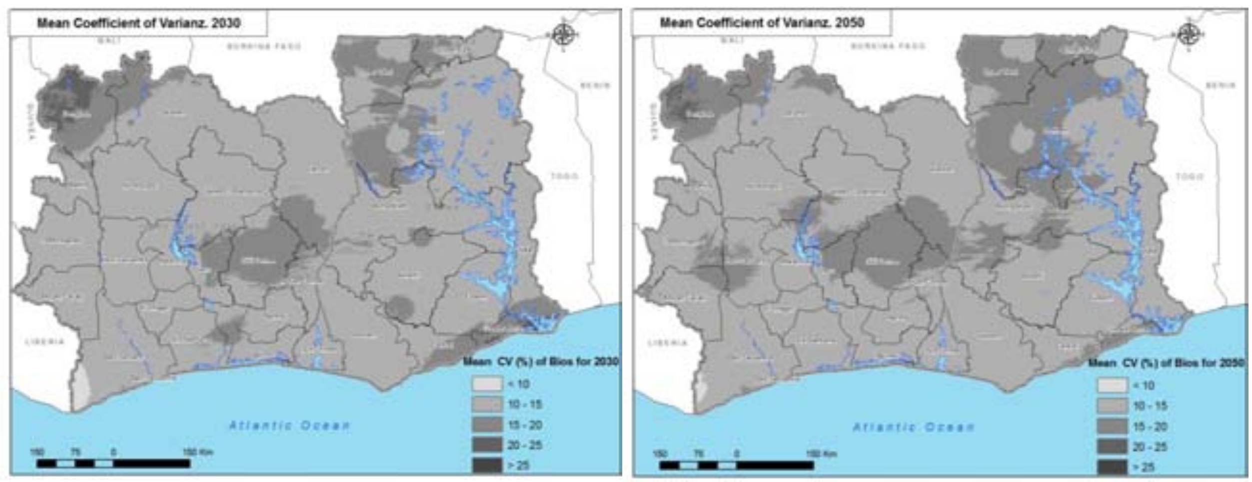

Figure 10: Mean coefficient of variance of bioclimatic variables for 2030 and 2050.

6.c Suitability change of cashew growing areas

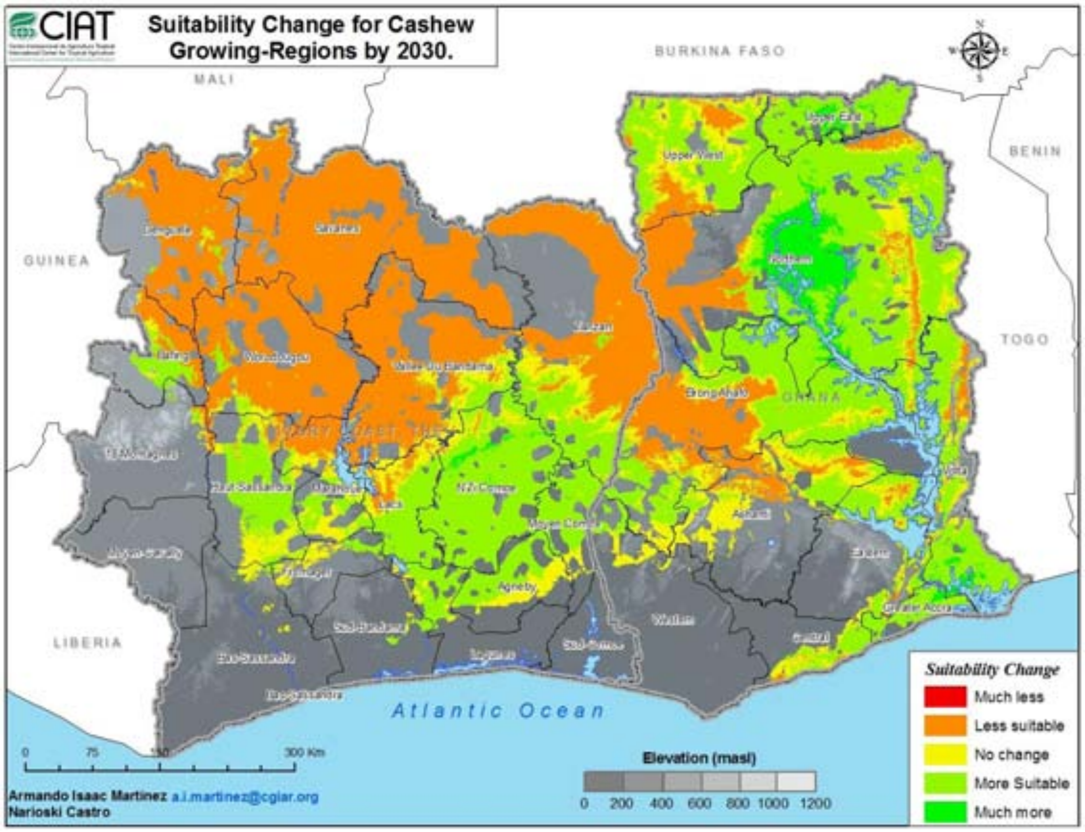

Figure 11: Change in suitability for cashew growing regions by 2030.

Figure 8 and 9 show the climate suitability for 2030 and 2050, while Figures 11 and 12 show the change in climate suitabilities by 2030 and 2050.

By 2030, the changes in the predicted suitability of cashew are mixed. There will be a decrease of climate suitability up to 40% compared with now in the Zanzan, Savanes and Denguele regions in Côte d'Ivoire. In contrast, there will be a increase of climate suitability up to 40% in the N´zicome, Moyen comoe, Agneby and Lacs regions of Côte d'Ivoire and in the Northern, Upper West and Upper East regions in Ghana. Suitability will increase by more than 40% in the East, West and Central Gonja Districts of Ghana(Figure 11).

By 2050, the climate suitability for cashews will decrease by up to 40% in the Savanes, Denguele and Worodougou regions in Côte d'Ivoire and the Techiman municipality between Sawla-Tuna-Kalba and the Bole districts of Ghana. Climate suitability for cashews will increase inAgneby, N´zi comoe, Moyen comoe and Lacs regions in Côte d'Ivoire and in the Upper East, Upper West, Northern, most districts in Brong Ahafo and some districts on the coastal regions in Ghana (Figure 12). The total area of increased suitability is greater than the area of decreased suitability.

The average suitability projected for the future varies by location. In Côte d'Ivoire, the northwest region loses climate suitability, while the southeast regions will gain suitability. In Ghana, most of the available areas gain climate suitability, except areas in Techiman municipality, Bole and Offinso districts. The magnitude of the changes is highly site dependent (Table 2).

Table2: Comparison between current and predicted suitability for three selected regions.

Region	Country	Current mean suitability (%)	Predicted suitability by 2050 (%)	Change in suitability (Mean %)
Savanes	Côte d'Ivoire	52	37	-15
N´zi Comoe	Côte d'Ivoire	16	75	59
Upper East	Ghana	22	79	57

The measure of agreement of the GCMs predicting changes in the same direction as the average of all models at a given location is between 80% - 100% in cashew-growing areas (Figure 13).

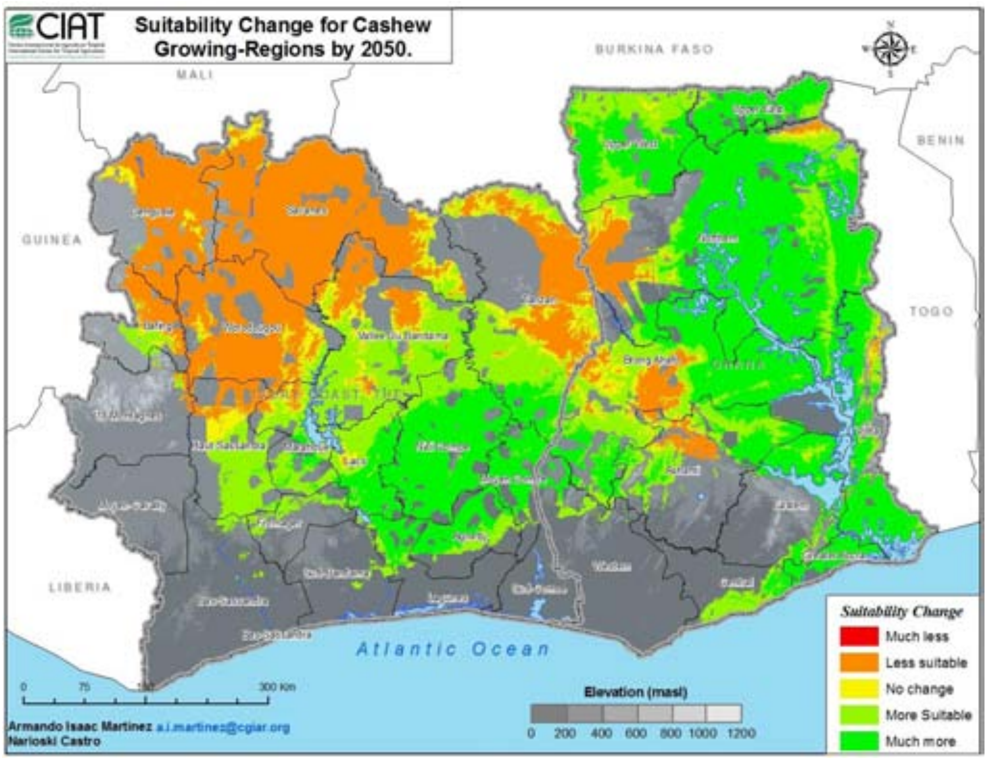

Figure 12: Suitability change for cashew growing regions by 2050.According to MAXENT, it is predicted to decrease the suitability by 2050 on northwest growing areas. But an increase it is predicted to most of areas available for cashew.

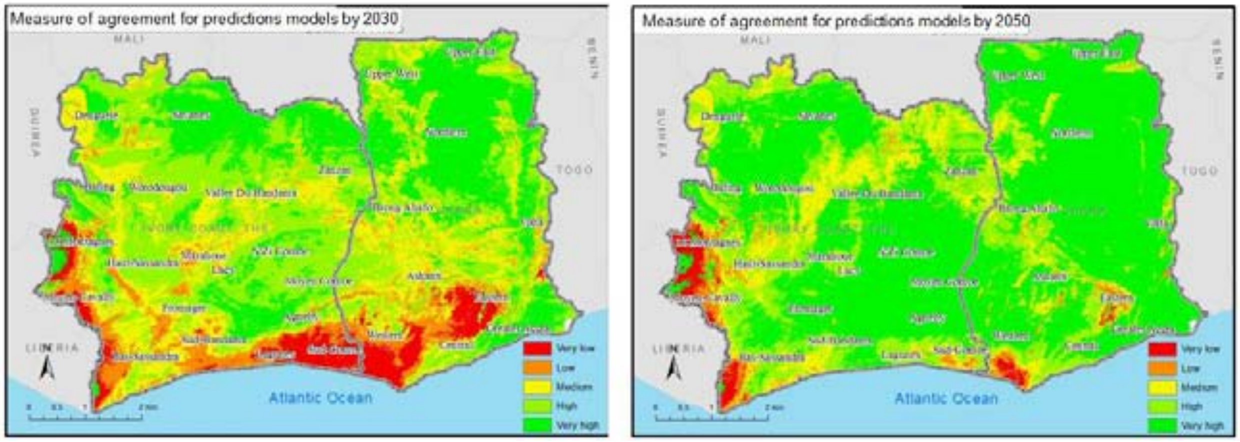

Figure 13: Measure of agreement of models predicting changes in the same direction as the average of all models at a given location for 2030 and 2050.

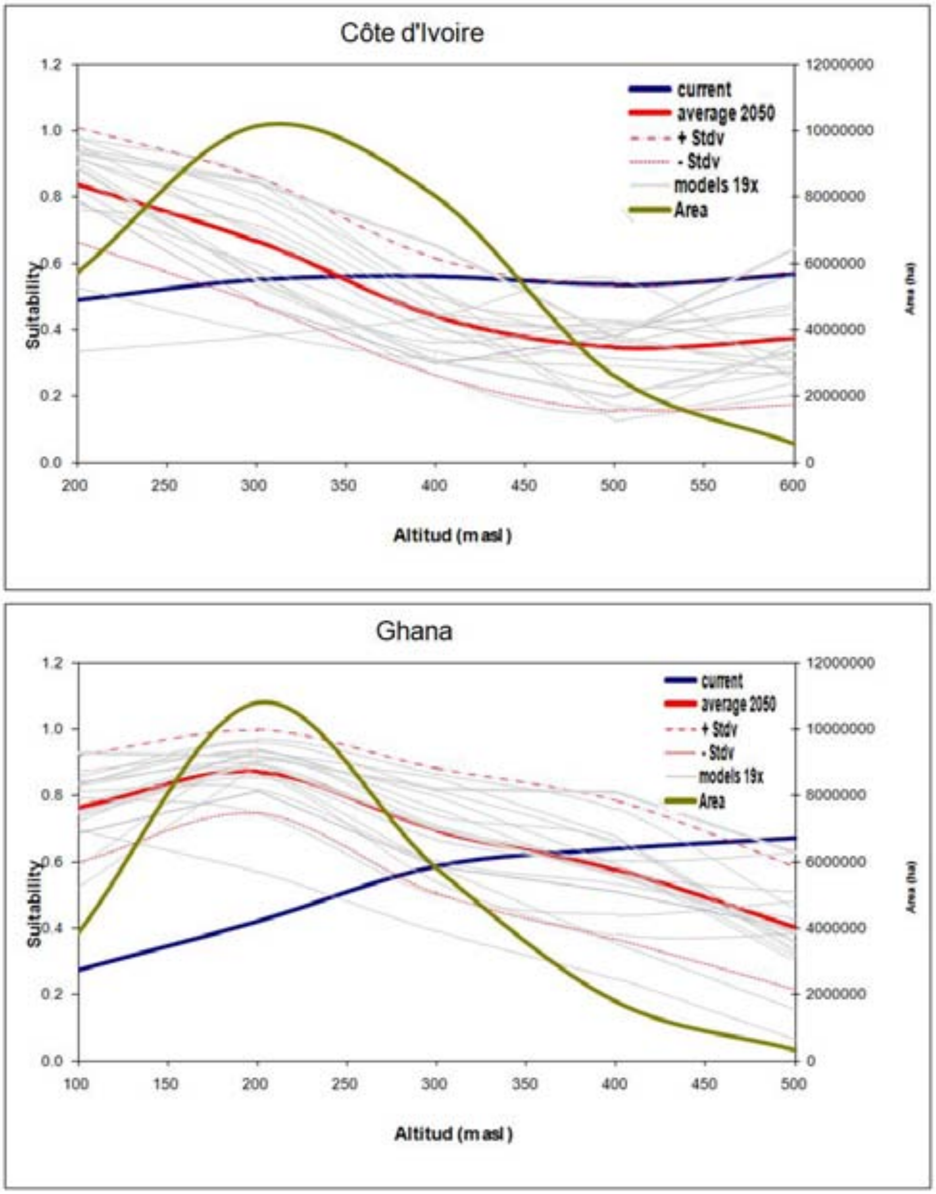

Figure 14: The relation between the climate suitability of cashew-growing regions and altitude for current climates, and those predicted for 2030 and 2050 in Ghana and Côte d'Ivoire. The blue line is for current conditions, the red for average suitability in 2050, the green line is the total area (available and not available for crop), and the gray lines are the predictions for 2050 for each GCM. The altitude for current cashew-growing areas in Ghana is between 100 – 500 masl and in Côte d'Ivoire is between 200 – 600 masl.

With climate change, cashews will gain suitability in the lowlands (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 cashew-growing areas is currently to 300 – 500 masl, but by 2050 will decrease to 100 – 350masl. Compared to today, by 2050 areas at altitudes between 350 – 500 masl will suffer the greatest decrease in suitability and the areas 150 – 250masl the highest increase in suitability (Figure 14).

Cashews grow well in areas with distinctive wet and dry seasons and with temperatures within a range of 20 – 34 °C, these should not exceed 38 °C(MOFA, 2006), with an optimum range of 24 – 30°C. (Dedzoe, 2001).

7 Result III: Environmental factors which drive cashew suitability

The step-wise regression analysis identified primarily the bioclimatic variables related to increasing temperature as drivers of the predicted shifts in suitability. The step-wise regression analysis for changes in suitability on observed sample points for 2050 identifies the temperature annual range as the main driving factor explaining53.8% of variability for negative change in suitability (Table 3).Sites with more than 20% in predicted loss of suitability presents an increase of 0.4 °C in this range, while sites that lose suitability between 1 – 20% present an increase of 0.5 °C.

The increases of the mean temperature of warmest quarter explain 77.6% for sites gaining suitability. It is predicted to reach a mean of 31.1 °C during this period. Increasing the CO_2may increase photosynthetic assimilation rates and reduce stomatal conductance (Pereira de Souza et al., 2005).

Table3: Contribution of different bioclimatic variables to the predicted shift in suitability for cashews in Ghana and Côte d'Ivoire, between current and the 2050 conditions in locations with decreasing and increasing suitability.

Variable	AdjustedR2	R2 due to variable	% of total variability	Present mean	Change by 2050s
Locations with decreasing suitability (n=379, 49.9 % of all observations)					
Bio 7 - Temperature Annual Range (Bio5 – Bio6)	0.1175	0.1175	53.8%	16.6 °C	0.6 °C
Bio 11 - Mean Temperature of Coldest Quarter	0.1859	0.0684	23.4%	25 °C	1.7 °C
Bio 4 - Temperature seasonality (standard deviation *100)	0.1348	-0.0511	7.9%	1329	354
Bio 5 - Maximum temperature of warmest month	0.2184	0.0836	7.6%	35.4 °C	2.7 °C
Bio 19 - Precipitation of Coldest Quarter	0.2019	-0.0165	7.3%	478 mm	-33 mm
Locations with increasing suitability (n=381, 50.1 % of all observations)					
Bio 10 - Mean Temperature of Warmest Quarter	0.1425	0.1181	77.6%	28.5 °C	2.6 °C
Bio 8 - Mean Temperature of Wettest Quarter	0.0244	0.0234	15.4%	25.6 °C	1.9 °C
Bio 5 - Maximum temperature of warmest month	0.1521	0.0096	6.3%	35.4 °C	2.7 °C
Bio 6 - Minimum temperature of coldest month	0.0010	0.0010	0.7%	18.8 °C	2.1 °C

8 Conclusions and Recommendations

8.a Conclusions

- In the cashew-growing regions of Ghana and Côte d'Ivoire, yearly and monthly minimum and maximum temperatures will increase by 2030 and will continue to increase progressively by 2050 (up to 2 °C). Changes in yearly and monthly rainfall will be trivial.
- The suitability within the current cashew-growing areas will increase by 2050, except in northwest of Côte d'Ivoire where it will decrease.
- Climate suitability for cashews will decrease quite seriously in some areas, mainly in Savanes, Denguele and Worodougou regions (Côte d'Ivoire)and in the Techiman municipality, the area between Sawla-Tuna-Kalba and the Bole districts (Ghana). Climate suitability for cashews will increase in Agneby, N´zi comoe, Moyen comoe and Lacs regions in Côte d'Ivoire and in Upper East, Upper West, Northern, most of districts in Brong Ahafo and some districts on coastal regions in Ghana.
- The mean temperature of warmest quarter, increasing up to 31.1 °C, is the main driving factor (77.6 %) for gaining suitability predicted for 2050.Photosynthesismay increase in response to increasing atmosphericCO_2concentrations and may reduce stomatal conductance increasing water-use efficiency, although higher temperatures will increase evaporative demand (Pereira de Souza et al., 2005).
- The optimum cashew-growing zone is currently at an altitude between 300 and 500 masl, which will decrease by 2050 to an altitude between 100 and 350 masl.

8.b Recommendations

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

For farmers' adaptation:

- Implement new technologies available mainly for germplasm to improve quality and quantity of yield;
- Implement an efficient management of soils, water and fertilizer application;
- As the current growing areas become drier, farmers should implement activities to prevent bushfires (Hennessy et al., 2005); and
- Farm diversification with alternative crops (citrus, yam, maize and millet), mainly to avoid monocrops, protect natural resources, and ensure food security(MOFA, 2006).

For researchers:

- Research on planting materials with better quality and quantity of yields and post-harvest management;
- 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 national policies for adaptation;

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

For governments

- Encourage the development of cashew through the access to credit for cashew producers;
- Promote research on post-harvest management and added value for cashews;
- Implement the awareness of climate change, by promoting and publishing research projects on climate change through campaigns of public information through national communications to the UNFCCC; and
- Support research and development on appropriate technologies to help farmers adapt to climate change

For the industry

- Implement a quality system for processing cashews;
- Promote and implement training and educational campaigns on quality of cashews; and
- Use the potential of these areas for cashews to attract new investment to the sector.

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.

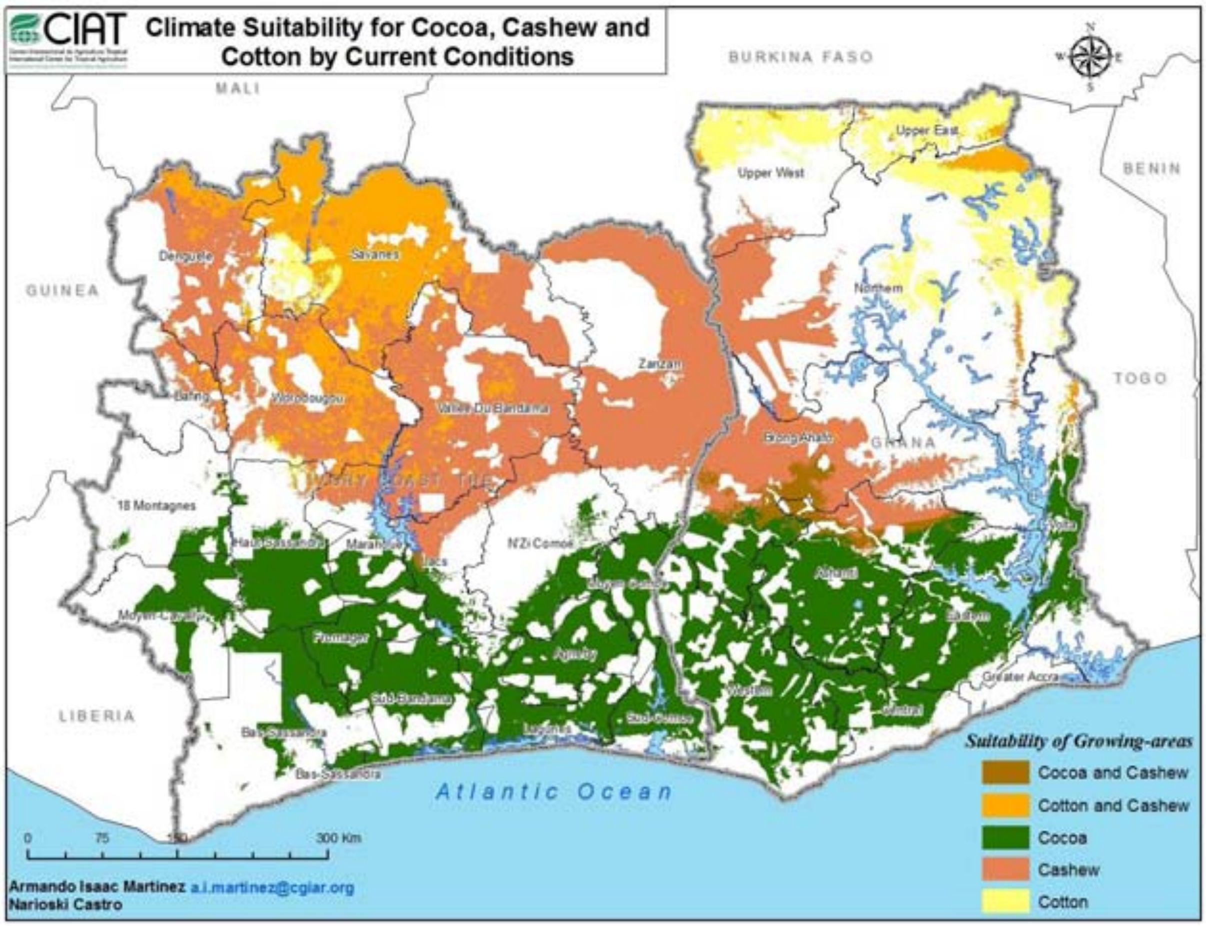

Figure 15: Current climate suitability for cocoa, cashew and cotton production in Ghana and Côte d'Ivoire. The climate suitability predictions do not include the protected areas, forest, urban and water bodies.

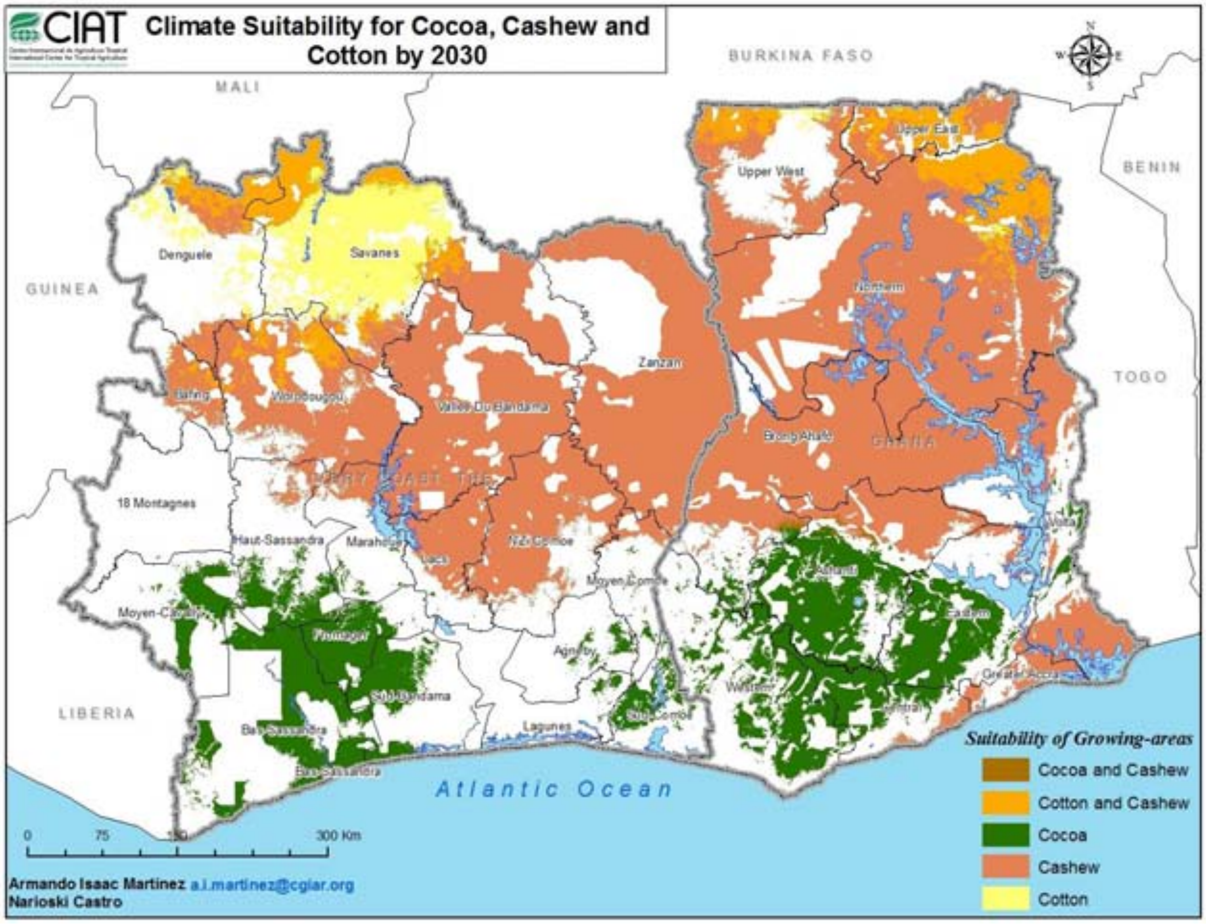

Figure 16: Climate suitability by 2030 for cocoa, cashew and cotton in Ghana and Côte d'Ivoire. The climate suitability predictions do not include the protected areas, forest, urban and water bodies.

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.

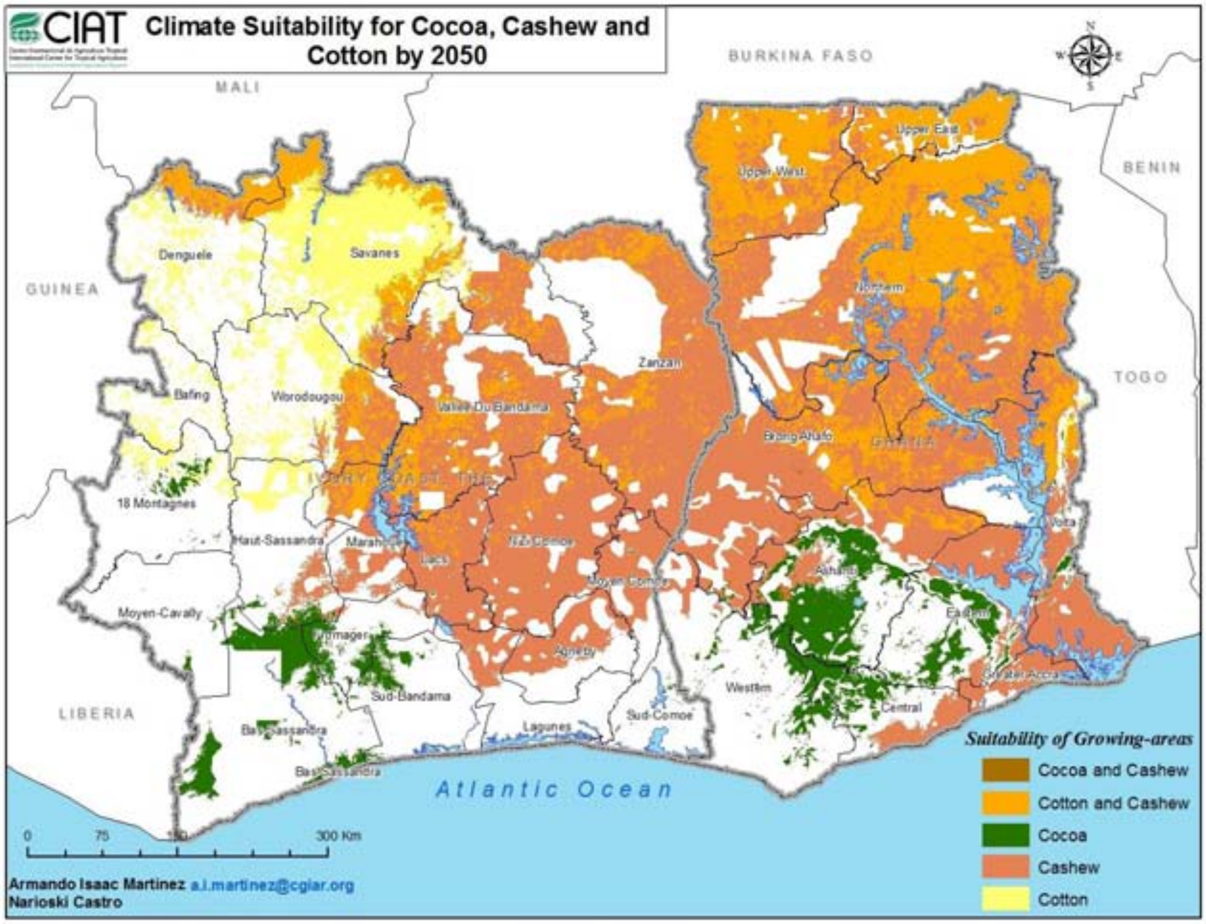

Figure 17: Climate suitability by 2050 for cocoa, cashew and cotton in Ghana and Côte d'Ivoire. The climate suitability predictions do not include the protected areas, forest, urban and water bodies.

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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Annex I: Consultations via email and during cashew and cotton 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?

Annex II: Summarized responses for model validation.

Table4: Summarized responses on current cashew distribution results conduced using MAXENT.

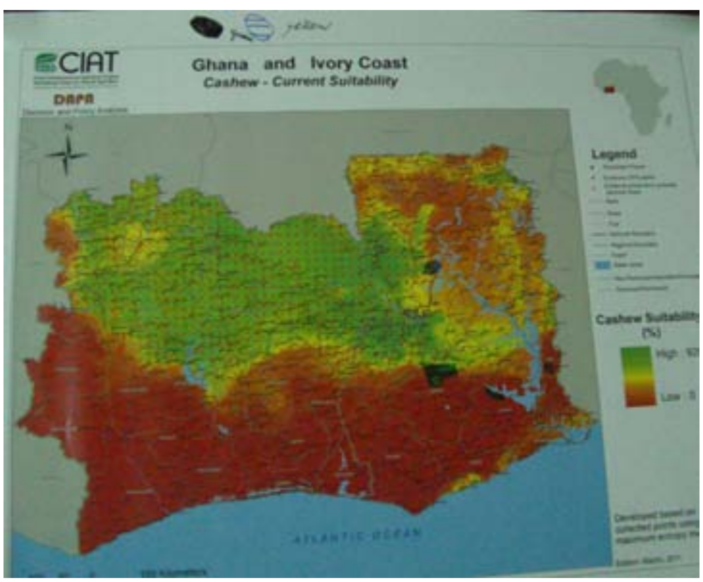
		Questionnaire Cashew						
		1	2	3	4	5	6	7
1	Country/ District	Tain District	Wenchi District	Tamale N/R	Bbole District	Berekum Municipal	Wenchi - B/A	Northern Rgion
2	Agree with the prediction of current suitability?	Very sustainable	Very suitable	Suitable	Marginal	Very Suitable	Suitable	Marginal
3	Any missing area		Areas are included by the group	Eastern corridor of Northern Region	No	Yes	No	No
3.1	Is missing area similar to other areas			Eastern Yendi, Nammba North, Nammba South		Offinso and Afram Plains. Both are quite green	Need to extend to south	
4	Any comments	cashew is barely a new crop and its cultivation is going to be upscaled to include the eastern corridor of the country. This increasing the suitability area	Send us results so we can apply		A true reflection of the existing situation			In additional to variable for cotton-bush fires

Annex III: List of summit participants and model validation

Table5: Contact list of participants of the cashew and cotton summit held in Accra, Ghana on 7 April, 2011.

Name	Organisation
Mr. William Biah	MOFA
Godfried Ohene-Mensah	MOFA
Mr. Ahmed Tijani Yusuf	MOFA
Mr. Francis Ennor	MOFA
Dr. Marshark Abdulai	SARI
Mr. Kwesi Adu	GCCFMA Ltd.
Chief Adam Tampuri	GCCFMA Ltd.
NII Chiery	GIZ- ACI
Organizers	
Peter	CIAT
Christian Mensah	AE-LBI
Eric Doe	AE-LBI

Annex IV: Work map of the summit



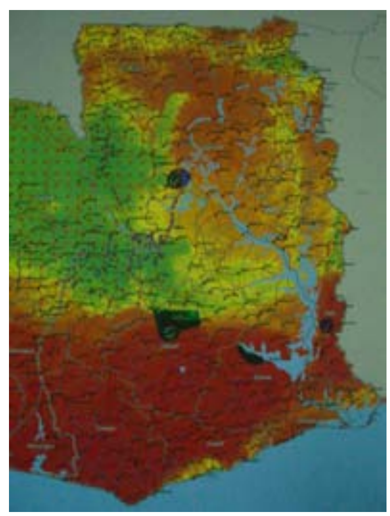


Figure 18: Climate Experts validated the MAXENT model by indicating performance of predictions during Cashew summit in Accra, Ghana on 7 April, 2011.