Global Impacts and Implications of Climate Change on Banana Production Systems

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ABSTRACT

There is now little doubt that climate change is a reality to which the world must adapt to. Predictions show that climate change will bring both opportunities and challenges for the agricultural sector, although most crops will suffer reductions in productivity with temperature changes > 2^{o}C. We present analyses on the impacts of climate change on banana production systems.

First, we query the likely impacts on banana production sites using 18 global climate models (GCMs) for the year 2050 derived from the 4th IPCC assessment report. All regions with banana production suffer increase in mean annual temperature within the range of 1.5 – 3.2^{o}C, with West African countries suffering the highest temperature increases. Precipitation changes are highly variables, with Carribean countries suffering significant reductions (>100mm less rainfall per year), whilst East Africa, South Asia and Ecuador having significant increases (>100mm). We also present decadal changes in growing environments for the world's major producing countries, demonstrating different fortunes for countries such as Cuba (significant drying trend) versus Colombia (steady increase in precipitation).

Second, we apply broad adaptation models (EcoCrop) for banana under current and future conditions. We show significant losses in climatic suitability for banana occurring in many lowland areas of Latin America (e.g. Amazon, Venezuela) and Africa (coastal West Africa), whilst suitability increases (but with high levels of uncertainty) for many sub-tropical zones (South Brazil, Australia, China) and coastal zones of Ecuador, Peru and Colombia. On average, global suitability for banana increases by 6%, but many of these gains occur in regions with low density of banana production.

Third, we analyse the impacts of climate change on potential climate-induced disease pressure for black leaf streak (black Sigatoka), and present some good news for banana producers currently losing productivity to this harmful disease. Almost all major banana producing regions become less impacted by black leaf streak as maximum temperatures in the hottest months exceed the heat thresholds of the fungus. The only areas negatively affected are in Southern Brazil, south-east Paraguay, northern Vietnam and central Myanmar.

Finally, we show some adaptation pathways that the research and production communities might take to adapt banana production to changing conditions. We develop a matrix of significant constraints that must be overcome in the future if banana production is to be sustained, or indeed enhanced if the opportunities that climate change presents are exploited fully.

Keywords: *climate change, banana, adaptation, suitability, black leaf streak.*

RESUMEN

Hay ahora muy pocas dudas de que el cambio climático es una realidad a la que el mundo debe adaptarse. Las predicciones de la comunidad cientifica muestran que el cambio climático traerá tanto oportunidades como retos para el sector agropecuario, especialmente considerando que muchos cultivos sufrirán reducciones en productividad si

los aumentos de temperatura llegan a más de 2ºC. Presentamos un análisis sobre los impactos del cambio climático en los sistemas de producción de banano.

En primer lugar, investigamos los impactos más probables en los sitios de producción bananera usando 18 modelos de clima global para el año 2050 del cuarto informe del IPCC (Panel Intergubernamental de Cambio Climático). Todas las regiones del mundo con producción bananera sufrirán un incremento en la temperatura media anual dentro de un rango de 1.5 a 3.2ºC. Los países de África occidental sufrirán los incrementos más notables en temperatura. Los cambios en precipitación son altamente variables; los países del Caribe sufrirán reducciones significativas (más de 100mm de disminución en la precipitación anual), entretanto el este de África, el sur de Asia y Ecuador tendrán aumentos de más de 100mm. Presentamos, además, cambios decadales en los ambientes de crecimiento de banano para los países de mayor producción mundial, lo que muestra fundamentalmente diferentes suertes para países como Cuba (tendencia de sequía significativa) en relación a Colombia y Ecuador (incremento gradual en precipitación).

En segundo lugar, dado que la capacidad de un cultivo para crecer en un medio ambiente determinado (adaptabilidad) es una función –en gran medida- del clima, aplicamos modelos de adaptación para banano bajo las condiciones actuales y futuras (año 2050): habrá pérdidas significativas en adaptabilidad climática para el cultivo en muchas tierras bajas de Latinoamérica (e.g. Amazonas, Venezuela) y África (costas de África occidental), mientras que en muchas zonas subtropicales (sur de Brasil, Australia, China) y costeras de Ecuador, Perú y Colombia la adaptabilidad se incrementa (aunque con bajos niveles de certeza). En promedio, la adaptabilidad del banano se incrementa en un 6%, pero muchos de los aumentos ocurren en regiones con baja densidad de cultivo.

En tercer lugar, analizamos los impactos del cambio climático en la presión climáticamente inducida de la Sigatoka Negra, cuyo hongo causante es altamente sensible a los cambios en la humedad, precipitación y temperatura. Hay algunas buenas noticias para los productores de banano que actualmente tienen pérdidas de productividad (o altos gastos en agroquímicos) debido a esta enfermedad: casi todas las grandes áreas de producción bananera sufrirán menos impacto de Sigatoka Negra. Esto será posible debido a que el aumento en las temperaturas máximas de los meses más calientes excederá los umbrales de calor dentro de los cuales el hongo tiene buen desarrollo. Las únicas áreas afectadas negativamente (aumento de presión de Sigatoka Negra) están en el sur de Brasil, el sureste de Paraguay, el norte de Vietnam y el centro de Myanmar.

Finalmente, mostramos algunos caminos de adaptación que la investigación y las comunidades productivas podrían tomar para adaptar la producción bananera a las condiciones cambiantes. Desarrollamos una matriz de principales limitaciones que debe ser satisfecha en el futuro si se pretende hacer sostenible la producción bananera a nivel mundial.

Palabras clave: *cambio climático, banano, adaptación, adaptabilidad, Sigatoka negra.*

INTRODUCTION

The 4th Assessment of the IPCC (IPCC, 2007) concluded that there is now no doubt that humans are affecting the climate. The report outlines how the climate has already changed over the past 100 years, in some cases quite significantly, and provides the latest results of modelling of the global climate system to predict the likely expected changes over the coming century. Depending on how rapidly the world reacts to the climate change crisis, temperatures are predicted to increase by as much as 6^{o}C on average across the globe to 2100. The implications of such changes are widespread, affecting almost all sectors of the economy. Regardless of whether the change be 2^{o}C or 6^{o}C, the various sectors of a country must address the problem by adapting the means by which they operate to maintain or enhance productivity in the face of change.

Agriculture is among the most vulnerable sectors of the economy to climate change due to its very direct reliance on the climate for productivity. The IPCC report suggests minor increases in productivity for a handful of well-studied major crops so long as temperatures do not rise more than 2^{o}C. Given the current evidence, and the latest state-of-the-art global climate models (GCMs), it is highly likely that by 2050 temperatures will have increased by an amount greater than 2^{o}C. The picture is therefore fairly bleak for many major crops, however we still know very little about the expected changes in productivity, especially for crops that come after the big 4: maize, wheat, barley and rice.

In order for society to take measures in adapting to climate change, it's important to have some understanding of what you are adapting to. For that, we rely on GCM predictions of future climate, which come with inevitable uncertainty. Here we provide an analysis of the best-bet impacts and implications of climate change on the banana sector globally, focussing on two specific aspects: productivity and black leaf streak disease prevalence.

MATERIALS AND METHODS

The analysis is comprised of four stages:

1. Compilation of expected changes in climate for current banana production zones
2. Niche-based mapping of suitability change for banana

3. Analysis of impacts of climate change on prevalence of black leaf streak
4. Analysis of some possible adaptation pathways to dealing with climate change

Current and future climate data

The IPCC 4th Assessment report was based on the results of 21 global climate models (GCMs), data for which are available through an IPCC interface (www.ipcc-data.org), or directly from the institutions developing each individual model. The spatial resolution of the GCM results is however inappropriate for analyzing the impacts on agriculture as in almost all cases grid cells of over 100km are used. This is especially the case in heterogeneous landscapes such as those found across the Andes, with just one cell covering the entire width of the range in some places.

Downscaling is therefore needed to provide higher-resolution surfaces of expected future climates if the true impacts of climate change on agriculture are to be understood. Two approaches are available for downscaling; 1) re-modeling of impacts using regional climate models (RCMs) based on boundary conditions provided by GCMs to generate climate surfaces with over 20km of spatial resolution for specific regions, or 2) statistical downscaling whereby resolution is reduced using interpolation and explicit knowledge of fine-scale climate distribution and correlations between major climatic variables. Whilst the use of RCMs is more robust from a climate science perspective, it requires significant re-processing, and RCMs are only available for a reduced number of GCM models. It is only realistic to include 1-2 RCMs in any analysis (due to the high processing requirements), and so in the context of this project the use of an RCM for only one GCM would result in the inability to quantify uncertainty in the analysis, which we feel is inappropriate. We therefore have used statistically downscaled data derived from a larger set of GCMs.

We downloaded and re-processed IPCC 4th Assessment climate change results from 18 of the most reputable GCMs (Table 1) and applied a statistical downscaling method to produce 10km, 5km and 1km resolution surfaces of future monthly climate (maximum, minimum, mean temperature and precipitation) for the time period representing 2020 (for 4 models) and 2050 (for 18 models). In both cases the emissions scenario A2a (business as usual) has been used.

Table 1 Global climate models used for the analysis

Originating Group(s)	Country	MODEL ID	OUR ID	GRID	Year
Bjerknes Centre for Climate Research	Norway	BCCR-BCM2.0	BCCR_BCM2	128x64	2050
Canadian Centre for Climate Modelling & Analysis	Canada	CGCM2.0	CCCMA_CGCM2	96x48	2020-2050
Canadian Centre for Climate Modelling & Analysis	Canada	CGCM3.1(T47)	CCCMA_CGCM3_1	96x48	2050
Canadian Centre for Climate Modelling & Analysis	Canada	CGCM3.1(T63)	CCCMA_CGCM3_1_T63	128x64	2050
Météo-France Centre National de Recherches Météorologiques	France	CNRM-CM3	CNRM_CM3	128x64	2050
CSIRO Atmospheric Research	Australia	CSIRO-MK2.0	CSIRO_MK2	64x32	2020
CSIRO Atmospheric Research	Australia	CSIRO-Mk3.0	CSIRO_MK3	192x96	2050
Max Planck Institute for Meteorology	Germany	ECHAM5/MPI-OM	MPI_ECHAM5	N/A	2050
Meteorological Institute of the University of Bonn Meteorological Research Institute of KMA	Germany Korea	ECHO-G	MIUB_ECHO_G	96x48	2050
LASG / Institute of Atmospheric Physics	China	FGOALS-g1.0	IAP_FGOALS_1_0_G	128x60	2050
US Dept. of Commerce NOAA Geophysical Fluid Dynamics Laboratory	USA	GFDL-CM2.0	GFDL_CM2_0	144x90	2050
US Dept. of Commerce NOAA Geophysical Fluid Dynamics Laboratory	USA	GFDL-CM2.0	GFDL_CM2_1	144x90	2050
NASA / Goddard Institute for Space Studies	USA	GISS-AOM	GISS_AOM	90x60	2050
Institut Pierre Simon Laplace	France	IPSL-CM4	IPSL_CM4	96x72	2050
Center for Climate System Research National Institute for Environmental Studies Frontier Research Center for Global Change (JAMSTEC)	Japan	MIROC3.2(hires)	MIROC3_2_HIRES	320x160	2050
Center for Climate System Research National Institute for Environmental Studies Frontier Research Center for Global Change (JAMSTEC)	Japan	MIROC3.2(medres)	MIROC3_2_MEDRES	128x64	2050
Meteorological Research Institute	Japan	MRI-CGCM2.3.2	MRI_CGCM2_3_2a	N/A	2050
National Center for Atmospheric Research	USA	PCM	NCAR_PCM1	128x64	2050
Hadley Centre for Climate Prediction and Research Met Office	UK	UKMO-HadCM3	HCCPR_HADCM3	96x73	2020-2050
Center for Climate System Research (CCSR) National Institute for Environmental Studies (NIES)	Japan	NIES-99	NIES-99	64x32	2020

The statistical downscaling has been performed using the WorldClim dataset for current climate (Hijmans *et al*., 2005, available at http://www.worldclim.org) and a spline interpolation technique. Specifically, the centroid of each GCM grid cell is calculated, and the anomaly in climate assigned to that point. A spline- algorithm is then used to interpolate between the points to the desired resolution. The higher-resolution anomaly is then summed to the current distribution of climate (derived from WorldClim) to produce a surface of future climate and 19 bioclimatic variables are finally derived from monthly downscaled variables according to Busby (1991). The method assumes that the current meso- distribution of climate remains the same, but that regionally there is a change in the baseline. Whilst in some specific cases this assumption may not hold true, for the great majority of sites it is unlikely that there will be a fundamental change in meso-scale climate variability.

In addition to working on changes in the climate baseline we also have available data on year-to-year variability in climate; an important component of climate change which can have significant impacts on agricultural production and food security. We downscaled monthly data from 8 GCMs for each year from the 20th century through to 2100.

Throughout the analysis, the use of 18 GCM models allow the framing of results in terms of the associated uncertainty in future climate.

Crop adaptability

We follow the methodology of Lane and Jarvis (2008) for examining the impacts of climate change on productivity. Physiologically-based mechanistic crop models are available for only a small percentage of the world's crops, and althoguh for banana such models already exists they are not currently applicable worldwide. In the absence of mechanistic crop models, the Ecorop model (http://ecocrop.fao.org/) provides a simple method to evaluate climate change impacts on a wide range of crops, including banana. The Ecocrop model contains information on the edafo-climatic requirements for 1,300 cultivated species considering optimal conditions and limits to adaptation. Ecocrop is implemented in DIVA-GIS (Hijmans *et al*., 2005) and has been interfaced with monthly precipitation and temperature data to permit mapping of suitability on a global scale based solely on climate data. We apply the banana ecocrop model for current conditions, and for the 18 future 2050 climatic conditions from the different models. We then calculate an average future suitability, and by looking at the difference between future and current adaptability we report a range of basic descriptive statistics on changes in adaptability in different countries and regions of the world. We also report uncertainty in our projected changes by calculating the coefficient of variation (proportion of the standard deviation in the predictions' average) in adaptability change between the 18 different climate models.

Changes in black sigatoka prevalence

We follow the methodology of Ramirez et al. (this volume) for analysing the changes in climatically-induced disease pressure from black leaf streak disease (BLS, or black sigatoka). Ramirez et al. (this volume) generated statistical models for predicting BLS disease pressure through analysis of field experimental data. We apply the same model to future climate conditions, and calculate the future level of BLS disease pressure for each of the 18 GCM future climates for 2050. Like for Ecocrop, we take an average and report the change in disease pressure through descriptive statistics for countries and regions, and also classify uncertainty using the coefficient of variation between GCM model predictions.

Adaptation pathways

A range of adaptation pathways exist for dealing with (and profitting from in some cases) the changes in climate. Here we only give examples of possible adaptation options, and is by far not an exhaustive list.

RESULTS AND DISCUSSION

Predicted climate changes in banana production zones

The GCM data for both 2020 and 2050 in banana production zones was queried to describe the likely changes for each banana producing country in the world (Table 2). On average, banana producing zones increase in precipitation by just 6mm of annual rainfall, although some countries suffer significant increase in precipitation (e.g. Indonesia, Pakistan, Kenya, Ecuador) and other quite significant decreases (e.g. Honduras, Nicaragua, Grenada). On the whole, Europe (sub-tropical banana zones) and the Caribbean suffer the greatest drying (reduction of 124mm and 110mm per annum), whilst Asia and Sub-Saharan Africa get the wettest (increase of 59mm and 42mm per annum respectively).

Temperatures increase by 2.3°C on average globally, though the increases are highest in North Africa (2.9°C), Europe (2.6°C) and sub-Saharan Africa (2.5°C). The Caribbean suffers the least temperature increase of 1.7°C.

Table 2 Descriptive changes in average climate for the banana production zones of each banana producing country in the world for 2050

Country	Region	Total precipitation change (mm)	Annual mean temperature change (°C)	Precipitation seasonality change	Consecutive dry months change	Precipitation coefficient of variation (%)	Temperature coefficient of variation (%)
Bangladesh		113.822	2.230	-4.297	0.0	**3.972**	**4.385**
Bhutan		135.103	2.651	-9.262	0.0	9.223	10.908
Brunei		14.258	1.783	1.070	0.0	**2.127**	**2.064**
Cambodia		20.366	2.070	0.576	0.0	**4.527**	**2.661**
China		52.539	2.394	-1.313	-1.0	5.668	6.326
Cyprus		-42.590	2.211	-7.392	1.0	11.703	**4.390**
India		185.577	2.413	-15.326	-1.0	8.921	**4.231**
Indonesia	Asia	185.577	2.413	-15.326	-1.0	8.921	**4.231**
Japan		42.806	2.209	1.720	1.0	**2.683**	**4.359**
Laos		33.169	2.213	-0.886	0.0	**4.353**	**4.245**
Malaysia		-0.434	1.848	1.322	0.0	**2.975**	**2.120**
Myanmar Burma		107.909	2.252	-6.038	0.0	**4.867**	**4.342**
Nepal		178.806	2.594	-7.156	0.0	9.329	5.390
Pakistan		257.852	3.013	-19.018	-1.0	51.713	5.809

Papua New Guinea		68.346	1.858	1.308	0.0	**3.827**	**2.462**
Philippines		37.752	1.697	0.503	0.0	**3.208**	**1.309**
Solomon Islands		145.589	1.586	0.848	0.0	7.693	**0.941**
Sri Lanka		41.959	1.747	1.824	0.0	**4.445**	**1.596**
St Vincent Grenadines		-138.300	1.559	0.206	1.0	9.424	**1.169**
Taiwan		11.933	1.764	2.180	0.0	**4.633**	**1.644**
Tanzania		101.217	2.277	-4.038	0.0	7.796	**3.715**
Thailand		41.497	2.138	-1.925	0.0	**4.833**	**3.282**
Turkey		-97.396	2.856	1.487	1.0	7.247	5.615
Vanuatu		-9.637	1.498	1.986	0.0	**4.183**	**1.033**
Vietnam		3.105	2.007	1.896	0.0	**3.276**	**3.030**
Australia	Australia	81.401	2.384	-0.496	0.0	12.514	**4.187**
Antigua and Barbuda		-86.311	1.535	5.433	1.0	13.653	**1.145**
Barbados		-105.667	1.562	2.679	1.0	11.495	**1.066**
Cuba		-72.869	1.768	2.862	0.0	8.344	**1.933**
Dominican Republic		-95.659	1.835	3.283	1.0	10.271	**1.985**
Dominicana	Caribbean	-129.420	1.546	1.300	0.0	8.718	**1.294**
Grenada		-139.639	1.589	0.194	0.0	10.385	**1.075**
Guadeloupe		-111.697	1.539	2.281	1.0	9.121	**1.271**
Haiti		-81.332	1.821	1.711	0.0	8.650	**2.230**
Jamaica		-73.158	1.726	2.910	1.0	5.506	**2.023**
St_Lucia		-127.657	1.572	0.952	0.0	9.884	**1.157**
Trinidad and Tobago		-186.898	1.998	1.704	1.0	10.460	**2.487**
Albania		-161.794	2.627	17.746	1.0	8.263	9.339
Bulgaria		-125.967	2.744	20.148	1.0	12.214	7.563
France		-106.611	2.594	10.389	1.0	**4.893**	6.618
Greece	Europe	-114.509	2.512	11.619	2.0	7.266	5.395
Macedonia		-138.139	2.792	24.306	1.0	13.552	7.174
Portugal		-109.854	2.332	10.154	1.0	8.029	5.276
Spain		-116.618	2.673	14.362	1.0	11.510	6.308
Argentina		47.917	2.590	-4.084	0.0	10.026	**4.181**
Belize		-145.478	2.205	2.800	0.0	7.501	**3.255**
Bolivia		-13.887	2.857	3.465	0.0	7.134	**4.315**
Brazil		1.029	2.576	1.844	0.0	5.562	**3.861**
Colombia		51.070	2.315	-2.015	0.0	**4.778**	**3.370**
Costa Rica		-67.955	2.080	-0.459	0.0	7.333	**2.291**
Ecuador		116.421	2.108	-3.294	0.0	6.058	**2.763**
El Salvador		-54.633	2.299	-3.097	0.0	7.238	**3.367**
Guatemala		-97.506	2.373	0.940	0.0	5.315	**3.607**
Guyana	Latin America	27.845	2.366	-2.802	0.0	8.092	**3.356**
Honduras		-120.022	2.308	2.745	0.0	7.926	**3.339**
Mexico		-81.117	2.317	0.884	0.0	5.097	**3.500**
Nicaragua		-132.153	2.288	-0.098	0.0	9.098	**2.779**
Panama		3.750	1.827	-2.100	-1.0	6.601	**2.456**
Paraguay		-13.223	2.569	6.784	0.0	7.732	**4.781**
Peru		80.894	2.687	0.688	0.0	7.475	**4.939**
Suriname		-116.689	2.282	6.481	0.6	14.046	**3.701**
Uruguay		49.741	2.107	8.315	1.0	8.836	5.186
Venezuela		-15.819	2.642	1.664	0.0	9.125	**4.076**
Algeria		48.214	3.230	17.650	1.0	31.982	6.774
Egypt	North Africa	28.587	2.481	29.036	1.0	31.687	5.548
Morocco		-79.992	2.872	8.227	1.0	20.259	6.955
Angola		2.392	2.536	-1.116	0.0	7.829	**3.748**
Benin		91.841	2.492	-10.936	-1.0	10.201	**3.639**
Botswana		10.287	3.011	-6.862	1.0	8.879	5.990
Burkina Faso	Sub Saharan Africa	73.264	2.638	-10.194	0.0	11.026	**4.023**
Burundi		141.892	2.363	-6.930	-0.1	12.665	**4.055**
Cameroon		18.791	2.308	-0.811	0.0	**2.672**	**3.545**

Central African Republic	28.846	2.436	-3.054	0.0	**3.568**	**3.534**
Chad	29.779	2.658	-5.229	0.0	6.525	**4.283**
Congo	-1.179	2.310	0.770	0.0	5.500	**3.197**
Equatorial Guinea	12.159	2.094	0.950	0.0	**3.595**	**3.151**
Eritrea	48.176	2.894	-14.500	0.0	29.630	**4.142**
Ethiopia	102.829	2.583	-10.116	-1.0	7.768	5.328
Gabon	11.454	2.140	0.059	0.0	**3.368**	**2.943**
Gaza Strip	-22.963	2.531	-0.630	1.0	20.392	6.081
Ghana	18.538	2.237	-2.858	0.0	7.093	**3.150**
Guinea	71.216	2.437	-4.002	0.0	6.777	**3.759**
Guinea-Bissau	71.216	2.437	-4.002	0.0	6.777	**3.759**
Ivory Coast	35.465	2.284	-3.550	0.0	7.146	**3.568**
Kenya	161.460	2.299	-6.617	-1.0	12.224	5.168
Lesotho	-18.356	2.602	6.588	0.0	7.350	5.807
Libera	57.931	2.106	-1.002	0.0	6.511	**2.934**
Madagascar	-20.614	2.051	1.874	0.0	**1.689**	**2.749**
Malawi	36.549	2.491	-5.269	0.0	5.471	**3.596**
Mali	98.321	2.697	-9.272	0.0	8.084	**4.464**
Mozambique	-29.805	2.348	3.880	0.0	**3.841**	**2.959**
Namibia	11.914	2.965	-4.950	1.0	9.162	**4.961**
Niger	54.674	2.774	-10.623	-1.0	10.832	**4.984**
Nigeria	45.141	2.503	-5.674	0.0	5.257	**3.992**
Rwanda	112.023	2.317	-3.950	-1.0	11.990	**3.995**
Senegal	22.712	2.345	-4.446	0.0	10.012	**3.380**
Sierra Leone	80.511	2.181	-1.570	0.0	6.298	**2.915**
South Africa	-20.830	2.462	3.590	0.0	5.955	**4.901**
Sudan	48.105	2.633	-9.535	0.0	5.901	**4.126**
Swaziland	-39.772	2.235	6.802	1.0	6.069	**4.256**
Togo	80.770	2.387	-7.057	-1.0	11.095	**3.234**
Uganda	128.660	2.282	-3.062	-1.0	12.693	**4.142**
Zaire	41.748	2.378	-2.041	0.0	**2.474**	**3.703**
Zambia	44.663	2.515	-5.771	0.0	5.308	**3.843**
Zimbabwe	10.340	2.804	-5.363	0.0	6.738	**4.960**

Examining the yearly time-series of change, the climate change trajectories of some banana producing regions for specific countries can be seen (Figure 1). On the whole the trends are fairly gradual and linear, although for some countries there is significant yearly and decadal variability in climate (e.g. Vanuatu). Other countries have non linear changes, for example in Japan where it gets slightly dryer before the trend changes towards increase in precipitation around 2050.

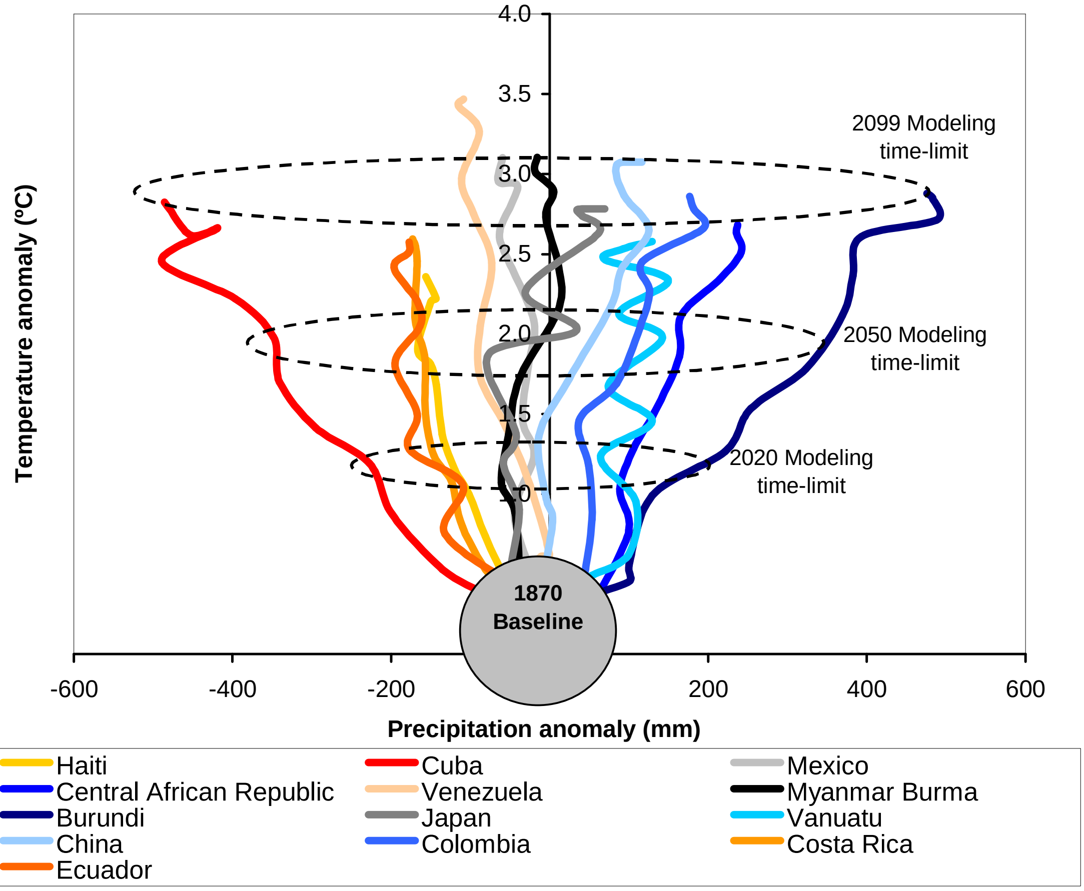

Figure 1 Yearly-time series of changes in climate for selected countries using the NCAR-CCM3 GCM model

Impacts on crop adaptability

The results of the Ecocrop model demonstrate an average increase of 6% in climatic suitability for bananas globally. The average increase in suitability for the ten highest producing countries is also 6%, though it is sub-tropical banana growing regions in China, Brazil and India that contribute most to this increase. Thailand and Colombia both suffer slight decreases in suitability (-5% and -2% respectively). The biggest winners are in Sub-Saharan Africa, especially Kenya (+23%), Rwanda (+23%), Uganda (+24%) and Ethiopia (20%), and sub-tropical Latin America (e.g Paraguay with an increase of 26%). The biggest losers are in the Caribbean (e.g. Barbados with -9% change), SE Asia (e.g.

Cambodia with -6% change) and West Africa (e.g. Togo with -8% change). The changes in banana suitability are shown as a map in Figure 2.

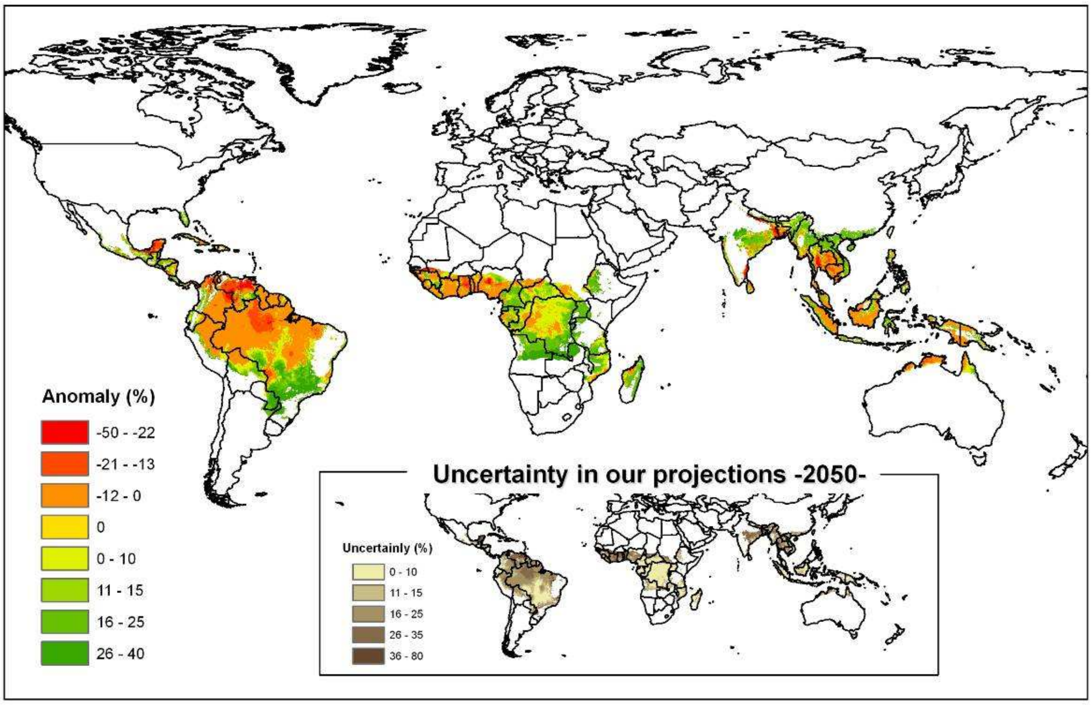

Figure 2 Changes in climatic suitability for banana across the globe for 2050

There is considerable variability in changes within countries (Figure 3). All regions of China, Burundi, Taiwan and Vanuatu experience increases in suitability, whereas in Venezuela almost all regions suffer decreases. The remainder of countries tend to have a range of impacts, with some regions increasing in suitability and others decreasing.

On the whole, the modelling of crop adaptability show that the 2050 climate has the potential to harbor more banana production, but significant shifts in the current distribution of banana are required to achieve such increases. These changes would require the expansion of banana production in some countries, decrease in others, and within countries there is evidence of significant shifting importance of different regions.

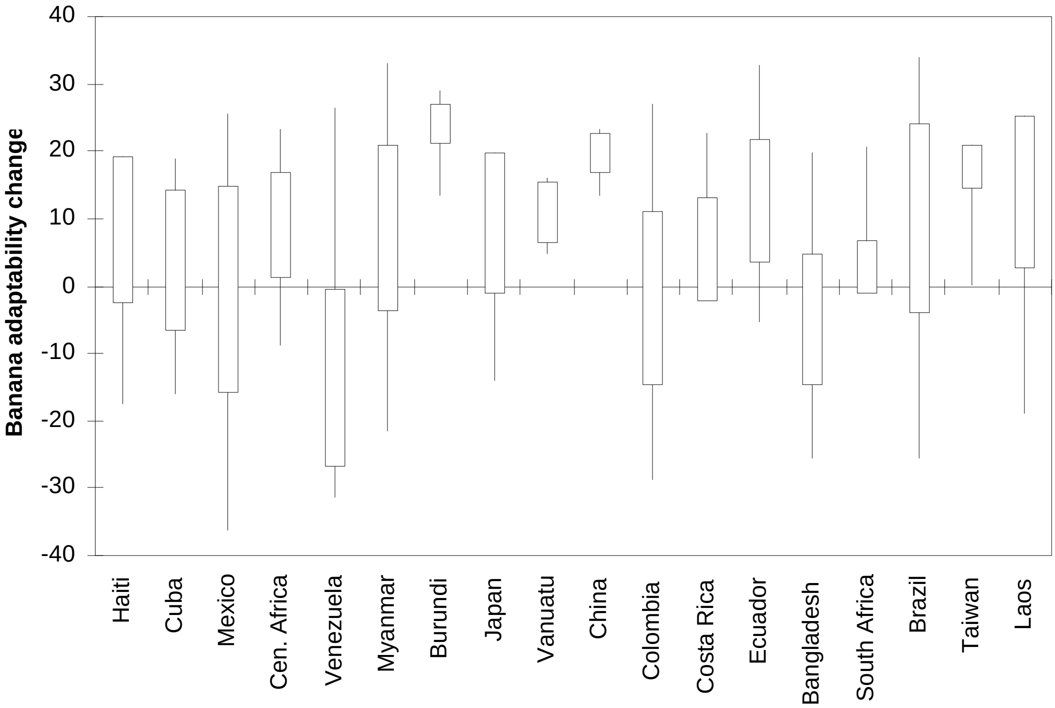

Figure 3 Projected changes in banana climatic suitability for 2050 for selected countries, bars representing within country range and extremes**.**

Impacts on black sigatoka

Following the model of Ramirez et al. (this volume) the impacts of climate change on black leaf streak disease pressure indicate an average global decrease of 1.3%, and 3% in the top-ten producing nations. The picture of change is almost the opposite as that for climatic suitability for production – sub-tropical regions which currently do not suffer from black leaf streak become much more suitable as low temperature thresholds are exceeded and the disease becomes more prevalent. Almost all tropical regions are predicted to experience less pressure form sigatoka as increases in temperature push the maximum temperatures above the threshold for the fungal disease. The biggest losers are China (23% increase in disease pressure), Taiwan (22% increase), Swaziland (51% increase), South Africa (31% increase), and Paraguay (22% increase). Almost all tropical countries experience decreases of 3-8% in disease pressure. The results are shown in a map (Figure 4), and for selected countries the mean and ranges of chnages are shown (Figure 5).

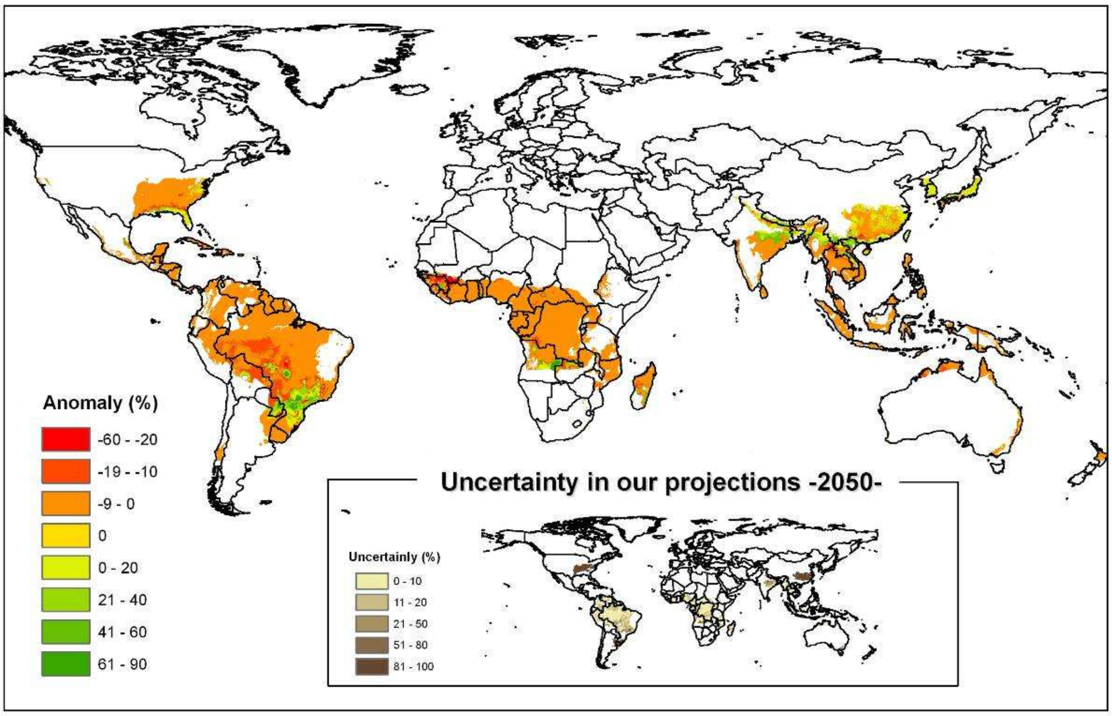

Figure 4 Changes in climatic suitability for black leaf streak disease across the globe for 2050

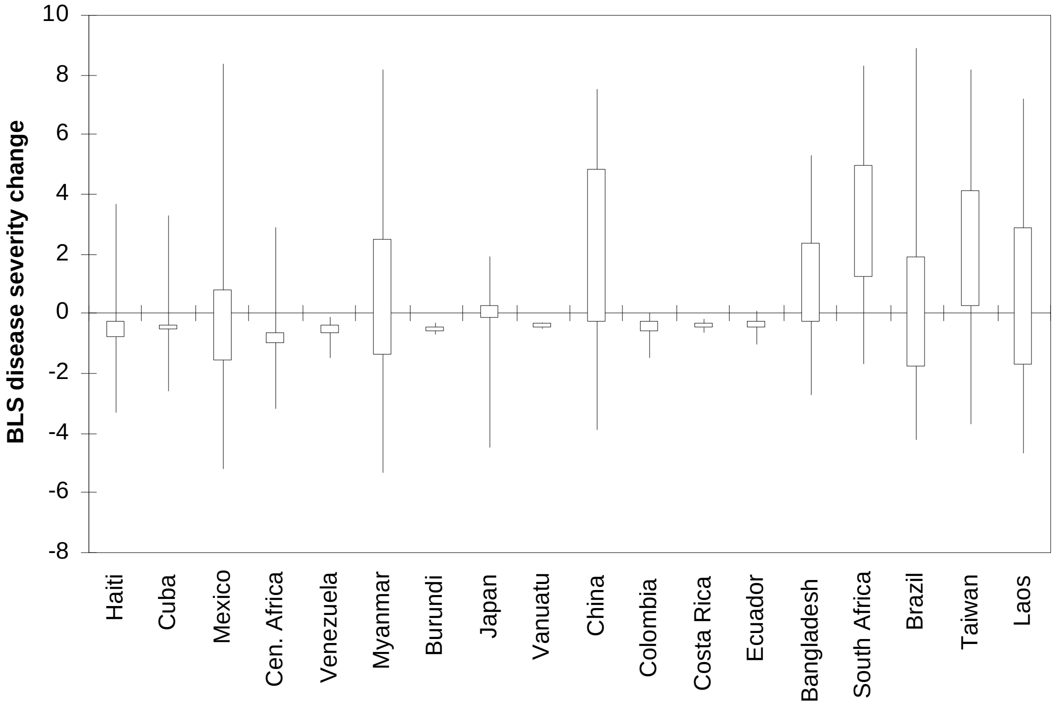

Figure 5 Projected changes in black leaf streak disease suitability for 2050 for selected countries, bars representing within country range and extremes**.**

Adaptation pathways

A range of adaptation pathways become evident from the above results. The pathways are largely site-specific, and depend on the current banana cropping systems and the predicted changes. In simple terms, the following three options, in order of severity, would be required:

1. Change crop management
2. Varietal change
3. Migrate to different zone or change crop

With increasing magnitudes of expected changes, different severity of adaptation measures are needed. As a worst case resort banana producers may need to relocate their crop, or change to a different crop altogether. However, in some cases these pathways may be designed to maximise the potential rather than mitigate negative changes.

Cross-cutting across these three types of adaptation is the potential of research and development to provide novel responses to climatic changes. These may lie in the development of new management regimes, promotion of precision and site-specific agricultural approaches that match the management to site-specific edafo-climatic variability, or in technology development, including breeding of new varieties with novel biotic and abiotic traits.

CONCLUSIONS

We present here the results of a modelling exercise to understand the impacts and implications of climate change on banana productivity and black leaf streak disease pressure. We show that climate change is not all bad news for the banana sector, with average increases in crop suitability, and significant decreases in black sigatoka disease pressure for many tropical countries. However, there are some hotspots where significant problems are likely to be experienced, requiring quite significant adaptations in order to overcome the challenges of climate change.

The analysis shown here looks only at two components of the banana production system: adaptability and black leaf streak. Many other facets of the production system have not been analysed and may have even greater significance to the banana sector. No matter what the predictions say, change is inevitable. The banana sector must continually adapt to changing biophysical conditions as well as social and economic changes which have plagued the banana sector in the past decades and will continue to do, most likely at a faster rate than climate change. Nevertheless, fundamental changes in the climate baseline to 2050 will require fundamental changes in production systems, and will likely have profound impacts on the global balance of production, especially with the increasing role of sub-tropical banana production.

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