Approach and methodology for climate risk assessments

For select crops including: canola, corn, oats, potato, soybean, sugar beet, sugarcane sunflower, and wheat

Prepared by the Alliance of Bioversity-CIAT

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Objective of the climate risk assessments

Climate change can intensify already existing challenges for farmers and suppliers across the world. Impacts of climate change, in the form of higher temperatures and highly varied precipitation will significantly affect crop performance. There is an urgent need from decision makers and farmers for detailed information on magnitude of climate change impacts, strategy for climate change adaptation, and implication on business operation. The Alliance of Bioversity-CIAT carried out the climate risk study with the aim to increase understanding within the supply chain of local risks and opportunities arising from climate change and creating a resilient farming system.

The goal of this methodology document is to make the study's approach transparent and accessible by users of the online Climate Impact Tool. Section I covers background information on the climate data used in the analyses and the advantages of this data in a science-based approach. Section II describes how the climate data is used in a specific agri-climatic modelling approach for climate suitability to potato crop. Section III describes the wider-reaching approach to anticipate climate impact on supplier sourced commodities more generally.

I. Modelling approach to understand the influence of climate change and variability on crop productivity

Overall approach

An improved understanding of the resilience of global crop production and how this may shift with climate change is urgently needed. Two main categories of factors that have great influence on plant growth as well as on the increase of crop yield/production are biotic and abiotic factors. Biotic factors (e.g., crop variety) and abiotic factors (e.g., temperature, rain, humidity, solar radiation, soil moisture etc.) affect plant growth and crop yield. Agricultural crops normally undergo a series of physiological processes during phenological stages of their life cycles that are sensitive to different environmental and climate conditions.

Several studies indicate strong associations between climate change and agricultural crops, either by using empirical (statistical) models, mechanistic (process-based) approaches or a combination of both. However, there are only a few studies that focus on this relationship at the plot level over large domains or countries due to lack of data, underscoring the importance and value of these data. Empirical models can be used to predict how these factors drive crop yields (Schlenker and Roberts 2009; Lobell and Burke 2010; Lobell et al. 2011; Urban et al. 2012; Osborne and Wheeler 2013; Moore and Lobell 2014; Ray et al. 2015). These models use local environmental conditions, including climate data as well as all available grower data. Previous research has shown that these empirical models are well-suited to determine the impact of climate and agricultural practices on growth and development, and that they can be a useful tool to assess the long-term impact of climate and associated environmental risks on crop yield.

For crops sourced directly, we are able to use the large amount of direct grower data in the PepsiCo-CGIAR partnership to run empirical models. Empirical modelling allows us to leverage extensive potato grower data from direct crop souring teams in 10 countries across different climatic zones. Generalized Additive regression Models (GAMs), are selected over other statistical and machine learning methods because of their flexibility in modelling non-linear relationships and to identify the most limiting factors of yield. The outputs from GAMs are used to map climatically suitable growing regions for potato. This suitability map is then coupled with business impact modelling to tailor business case adaptation recommendations for each country. Detailed steps for the agri-climatic modelling approach for direct crops are described in Section II of this document.

For crops usually sourced indirectly through suppliers, no detailed plot-level grower data is available to inform an agri-climatic modelling approach. Instead, the study on supplier sourced crops leverages public data from scientific literature and expert interviews to give a global view on more than 8 crops in over 50 countries. Harnessing the knowledge in the vast amount of scientific literature published on these crops globally, this proves to be a robust option in the absence of field data direct from growers' plots. As peer review literature for each crop and growing regions is gathered, relevant information on growing calendars, climate-crop sensitivities, best climate models, and adaptation practices is extracted and organized. This helps associate crop performance with specific types of climate risk and provides a case for adaptation priorities. Detailed steps for the climate risk assessment for supplier sourced crop approach are described in Section III of this document.

Climate data

Climate data can be separated into baseline (current) and future.

Baseline (current) climate data: Gridded climate data are acquired from the fifth generation of the European ReAnalysis, hereafter ERA5-Land (Muñoz-Sabater et al. 2021). Gridded climate data gives us access to daily high-resolution climatological data based on direct observations and over long time periods. The reason this is used is that there are not enough weather stations worldwide to cover every point on the earth. Gridded climate data solve this issue. These data describe the evolution of the water and energy cycles over land globally, at a 9km resolution. This is achieved through global high-resolution numerical modelling of the European Centre for Medium-Range Weather Forecasts (ECMWF) land surface model, which is driven by the downscaled meteorological forcing from the ERA5-Land climate reanalysis. Due to the scarcity of equally distributed on-the-ground weather stations, as well as the limitations point data incurs, ERA5-Land provides the best representation of high-resolution and reliable climate data source covering the globe. There are alternative gridded climate products providing similar data such as Worldclim and TerraClimate (Fick and Hijmans 2017; Abatzoglou et al. 2018), however these are only at monthly resolution.

Future climate data: Future daily climate are extracted from CMIP6 (Eyring et al. 2016). CMIP6 data (Coupled Model Intercomparison Project Phase 6 data) refers to a comprehensive set of climate model simulations that are designed to simulate the Earth's climate system and predict future climate change.

CMIP6 consists of 134 models from 53 modelling centers (Durack [2016] 2020). The scientific analyses from CMIP6 are used extensively in the Intergovernmental Panel on Climate Change 6th Assessment Report and are the most trusted source on future climate projections. These scenarios are highly flexible and allow for assessment of climate change impacts on crop production in an interpretable way while accounting for the uncertainty that is implicitly part of climate model projections and emission scenarios. The Climate Model Intercomparison Project (CMIP) was established in 1995 by the World Climate Research Program to provide climate scientists with a database of coupled Global Circulation Model (GCM) simulations. CMIP6 is the sixth and latest iteration of the leading international effort to bring together climate modelers from around the world to improve our understanding of past, present, and future climate change.

II. Direct crops

Process overview

For crops sourced directly (e.g., potato) we are able to leverage insights from plot-level grower data in the PepsiCo-CGIAR partnership to complete three major steps that result in:

1) determining the major climate drivers and limiting factors of potato crop yield/production in each country at high resolution;
2) mapping the suitability based on these major climate drivers and limiting factors both under baseline (1970-2000) as well as the future (2030) climate change scenarios, and;
3) modelling the business impacts of the cascading effects of climate change risk.

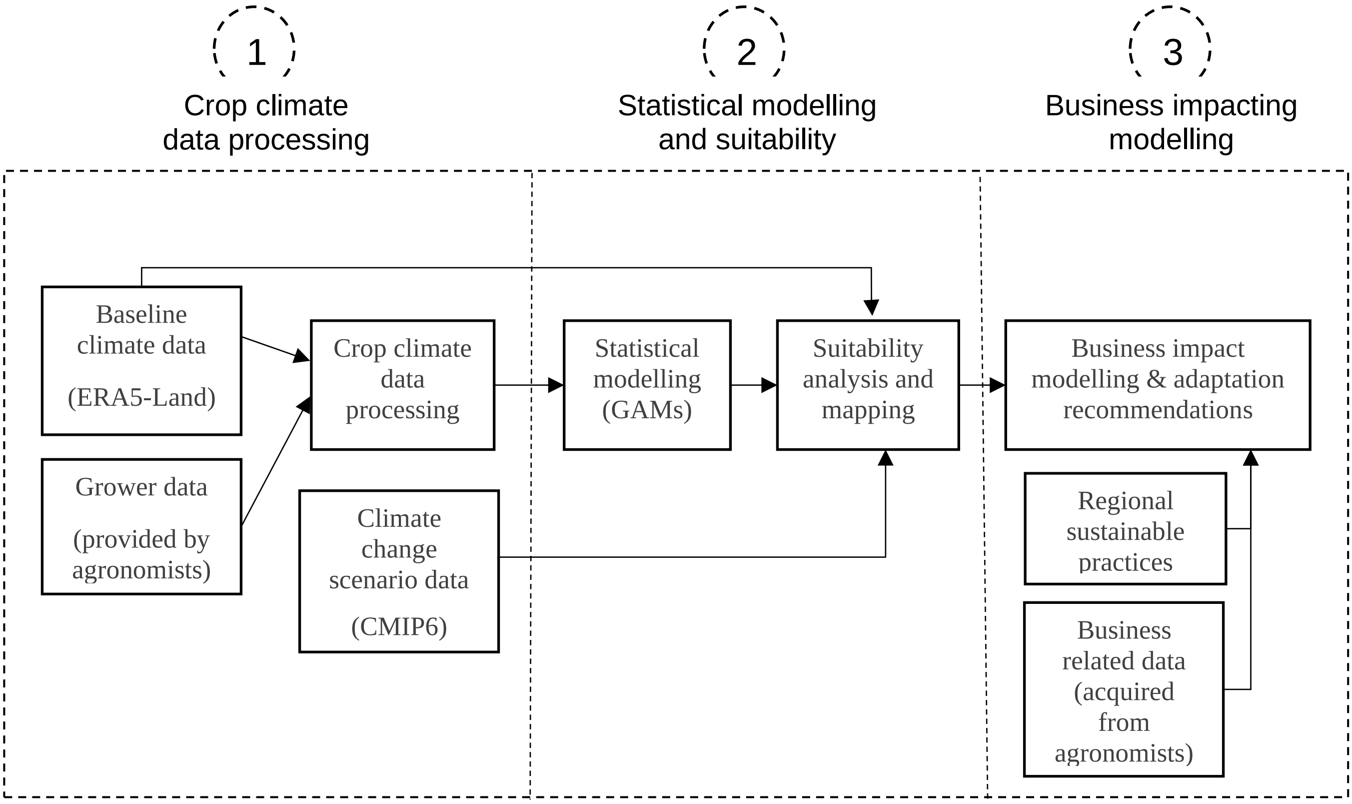

Figure 1. Agri-climatic modelling approach

1. Climate data processing for potato crop

Climate variables considered for the analysis are rainfall, air temperature (minimum, mean, maximum), diurnal temperature range, soil moisture, relative humidity, solar radiation, and other derived variables. These variables are extracted and aggregated for each country based on each of the grower location coordinates and corresponding planting and harvesting dates. Climate variables are calculated for both the whole growing season as well as each phenological phase. The phenological phases are vegetative, reproductive, and bulking. This process is replicated for both the baseline and future climate data. This is done in order to account for the more “sensitive” growth stages in the season.

2. Statistical modelling and suitability mapping

2.1 Statistical modelling

Generalized Additive regression Models (GAMs) (Hastie and Tibshirani 1986) are used together with multi-model selection (Fisher et al. 2018) to identify the key climate drivers for each country and regions potato production while accounting for all available grower variables such as supplier, variety etc. The value and reason for selecting these models are outlined in the introduction. All analyses are carried out in R (R Core Team 2021). The GAM has the following equation, where:

$$\log(y_{ij}) = \beta_o + f_{(x_{ij})} + z_i\varphi + \epsilon_{ij}$$

$$\epsilon_{ij} \sim Gamma(\gamma)$$

$$\varphi \sim N(0,\text{ב})$$

Yields (y) are modelled as a non-linear (f) function of predictor variables (x) for each country (i) and year (j) using a Gaussian distribution with an Identity link. A random effect (φ) for each country (Zi) is included to account for the repeat measurements for each year at the country level. Random-effects control for non-independence by constraining non-independent observations to have the same intercept. For example, yield observations from a particular country or region, may be more similar (e.g., higher on average if soils and management techniques are better) relative to yield observations from other regions or countries. To account for temporal autocorrelation, 'year' is modelled as an autocorrelation structure of order. There are 24 climate variables (maximum temperature, minimum temperature, total rainfall, total soil moisture, diurnal temperature range and solar radiation for both the vegetative, reproductive, and bulking seasons) in the initial model selection. Model selection also accounts for multi-collinearity by ensuring no models included variables with a Pearson coefficient r > |0.5|. Model selection then ranks candidate models based on both Akaike information criterion (AIC) and Bayesian information criterion (BIC). The final GAM model is selected based on AIC and BIC and captures statistically significant climatic trends and drivers of potato yield. Results from the GAM are presented as smooth curves, where firstly the height of the response curve of each predictor provides an indication of the total amount of yield drive associated with a specific climate gradient/variable. Secondly, the slope of the smooth curve at a specific point provides an indication of how the rate of yield varies along the climate gradient/variable concerned.

2.2 Suitability mapping

From evaluating fitted GAM smooths and outcome statistics, a range-based approach is then used to classify crop-climate suitability into four categories: suitable, marginal, stressed, and unsuitable growing conditions. Suitability thresholds vary by country as the statistical modeling is done at the country level.

Based on the sensitivity of potato to climate variables from GAM modeling, we create suitability maps for both baseline (1970-2000) as well as the future (2030) scenarios. The change in suitability between baseline and future scenarios is also calculated to determine areas of opportunity and risk. These suitability maps are then created in an html format for them to be explored in a dynamic dashboard.

3. Business Impact modelling

The Business Impact Model uses scenario analysis to investigate the cascading effects of climate change risk on the performance of business. The impact is first assessed under a "business as usual" or reference-case scenario, in which no changes to farm management are introduced to cope with the risk. This is compared to a "climate resilience" or adaptation scenario in which reduced yield losses are estimated based on yield loss buffering effects documented in the literature or business data (e.g. from demo farm records). Recommended practices such as drip irrigation and improved varieties are taken into account in Climate Positive scenario. The process includes comprehensive and quantitative estimates of adaptation options and their costs, and benefits, potential opportunities given climate change. A main advantage of the model is an in-depth examination of various scenarios, allowing business leaders to test decisions and understand the scale of the potential impact with the most up-to-date information. A major limitation of the model is the difficulty to gather data for adaptation scenarios. Values are taken from a variety of sources, including literature, interviews with management, and interviews with subject matter experts.

Inputs:
Business data such as procurement volume, cost of production, and projected distribution of volumes across regions and seasons are required inputs for inferring the impact of climate risks to the business.

Suitability maps resulting from the climate analysis are used to assess regional and local climate risks, then prioritize site-specific adaptation practices and make long-term adaptation strategies. This approach involves understanding possible regional patterns of climate change and socioeconomic factors that drive or limit adoptability of the practices.

III. Supplier sourced crops

Process overview

Climate variability and change have significant implications for crop production, affecting crop yield and quality worldwide. With the Earth's climate continuously evolving, understanding the effects of climate extremes, such as droughts, floods, heatwaves, and frost, on crop yields has become increasingly crucial. The sensitivity of different crop types to environmental factors can result in varying extents of impacts of climate extremes on crop production. Therefore, understanding the unique sensitivities of different crop types to climate extremes as well as how these impact crops in the future is crucial for developing effective strategies to mitigate the negative impacts of climate change on agriculture.

To achieve this, a three-step approach is applied. In the first step, existing literature is compiled to understand the main growing seasons of each crop in each focal country and the extent of positive and negative impacts of climate factors on each specific crop yield. Then, the best climate models are identified to represent different countries' baseline and future (2030) climate. Finally, the compiled data and selected climate models are used to project the impact and adaptation practices on crop yields in each of the crops main growing season, which is visualized on an interactive dashboard. This approach enables stakeholders to better understand the impacts of climate extremes on crop yields and identify effective adaptation strategies to ensure food security and sustainable agriculture in the future.

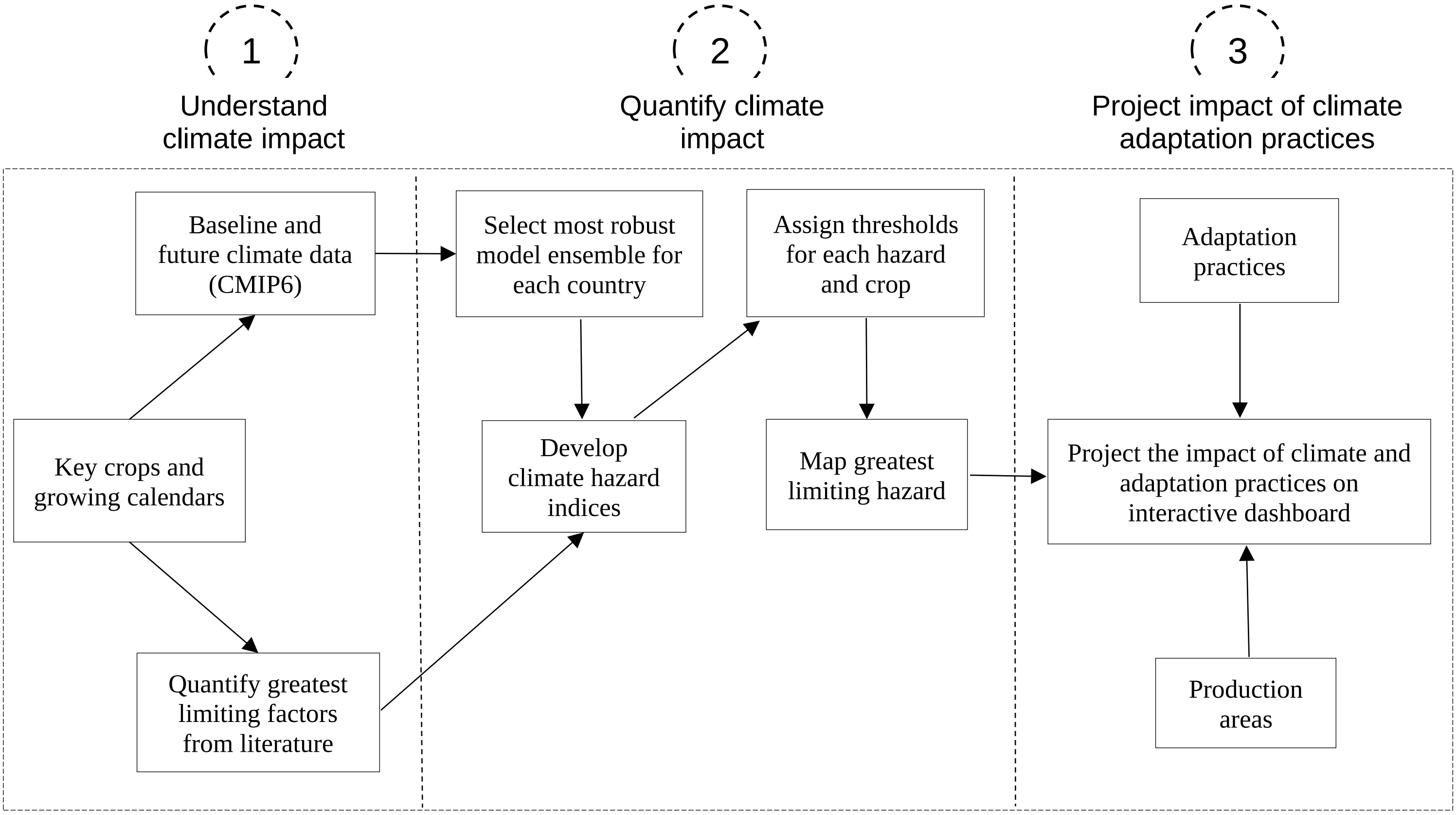

Figure 2. Climate risk and opportunity assessment methodology

1. Understand climate impact

Daily climate data are extracted for each crop per country. These data cover both the baseline (current climate) as well as future. The baseline period is considered the period from 1980-2000. The reason an average of 20 years is taken is to ensure that no biases are included by selecting a particular year which may be unrepresentatively hot, dry, cold or wet. The future climate period is also based on a 20 year span covering the years 2020-2040, which is typically used for a 2030 climate. Certain GCM's are more powerful than others depending on the geographic region. Therefore, we selected a different subset of GCM's for each region depending on the performance for that country or region. The selection is expanded on below in "Quantify climate impact". This data is used to produce four indices representing climate extremes that result in the largest net yield gain or loss risk for each jurisdiction during the growing season: heat, frost, flood, and drought. These risks are defined and calculated as follows:

Table 1. Climate risk definition

Climate risk	Definition
Heat stress	Heat stress is a climate extreme index which accounts for the number of days during the growing season that temperatures rise above the thermal limit for each crop type.
Frost risk	Frost risk is a climate extreme index which accounts for the number of days during the growing season that conditions drop below freezing.
Flood risk	Flood risk is a climate extreme index which accounts for the total amount of precipitation accumulated within a consecutive 5-day period during the growing season.
Drought risk	Drought risk is a climate extreme index that accounts for both precipitation and evapotranspiration during the growing season.

In addition, the growing season, or the period between planting dates and harvesting dates, varied for each crop and country. This information is gathered from peer-review papers and databases from official sources. The list of reference sources for growing season is detailed in Annex D.

2. Quantify climate impact

A systematic review methodology is applied to assess all existing literature on crop limits and limiting factors to quantify the greatest limiting factors and ranges on crop yield. To achieve this, a comprehensive search of scientific databases is carried out, including peer-reviewed articles, conference proceedings, and scientific reports. The retrieved articles are then screened for relevance and quality and selected those that met our inclusion criteria. Specific data on crop types, yield, and limiting factors are extracted from the selected articles and synthesized using meta-analysis techniques. This approach enables the quantitative estimation of the relative importance of different climate risks (heat, frost, flood, drought) and their ranges on crop yield across different crop types, utilizing the vast amount of published literature on these crops. All crops and countries are shown below in Table 1. The climate risks' ranges on different crops are specified in Annex E and the list of literature on limiting factors is detailed in Annex F.

Table 2. List of crops and countries included in the scope thus far

Sector	Corn	Oats	Wheat	Sugar beet	Canola	Soy	Sugar-cane	Sun-flower	Table grape
North America	x	x	x	x	x	x	x	x	
Europe & Russia	x	x	x	x	x	x		x	
South Africa	x	x	x						x
Egypt	x			x					
Brazil	x		x			x	x		
India	x								
Australia	x	x	x		x				

The accuracy of GCMs in predicting climate conditions in different countries depends on a complex interplay of data quality, model assumptions and emission scenarios. Using all available academic literature, GCMs are gathered according to their accuracy per country, per region and all selected GCMs are averaged to produce an ensemble frost, drought, heat, and flood risk index per country. This ensures that only the best models are selected to better capture the complexity of the Earth's climate system and improves the ability to predict future climate change. The list of literature for GCMs assessment is detailed in Annex G.

3. Project impact of climate adaptation practices

Based on the criteria established in the "Quantify climate impact" section above, the crop yield of each crop is calculated for specific administrative levels, using categories of extremely high yield loss, high yield loss, moderate yield loss, no change, moderate yield gain, high yield gain, and extremely high yield gain. This process is conducted for both the projected climate conditions and a hypothetical simulation of a scenario that visualizes the potential adaptation impact of regenerative agriculture practices, referred to as a resilient scenario.

The resilient scenario is created based on a systematic literature review. For each location, a search is conducted to identify a range of options that can reduce the risk and enhance farm resilience. These options include changes in agricultural practices such as drip irrigation, cover cropping, or pest & disease scouting, etc. With the literature review, current adoption rates are assessed to determine the practices' feasibility and opportunity to increase climate resilience. The process also involves assessing the potential benefits and limitations of each option with regards to their impact on livelihoods, greenhouse gas reduction and biodiversity. Based on previous assessments, a list of adaptation options is generated and prioritized with multiple factors across their feasibility, sustainability, and constraints to develop implementation plan. After identifying adaptation measures for each specific region, adaptation options are integrated into the base map with their yield benefits. Adaptation scenarios are then overlayed to see how effectively packages of adaptation options would reduce climate risks. The list of literature used for the resilient pathway development is detailed in Annex C.

Subsequently, these maps are also overlayed by production area (Monfreda, Ramankutty, and Foley 2008) to visualize the magnitude of the impact as well as the simulation of a potential resilient scenario. The results are integrated into an interactive dashboard. Within the dashboard each admin level is mapped according to its greatest limiting factor.

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Annex C – Business impact and adaptations

Agri-climatic modelling

Potato

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Annex D – Crop calendars and data sources

Country	Growing period	Crop	Data sources
South Africa	November-May	Maize	https://ipad.fas.usda.gov/ogamaps/cropcalendar.aspx https://www.fao.org/giews/countrybrief/ https://www.nda.agric.za/docs/Brochures/Oats.pdf https://americansugarbeet.org/who-we-are/what-is-sugarbeet/ https://www.actascientific.com/ASAG/pdf/ASAG-06-1090.pdf https://www.uscanola.com/crop-production/spring-and-winter-canola/ https://www.ifastat.org https://api.ifastat.org/reports/download/13300 **Sacks, W.J.**, D. Deryng, J.A. Foley, and N. Ramankutty (2010). Crop planting dates: an analysis of global patterns. Global Ecology and Biogeography 19, 607-620. DOI: 10.1111/j.1466-8238.2010.00551.x.
South Africa	May-December	Oats	
South Africa	May-November	Wheat	
Europe and Russia	April-October	Maize, Oats, Sugar beet, Soy, Sunflower	
Europe and Russia	Jan-December	Wheat, Canola	
Egypt	May-November	Maize	
Egypt	September-April	Sugar beet	
Brazil	October-August	Maize	
Brazil	April-December	Wheat	
Brazil	October-May	Soybean	
Brazil	Jan-December	Sugarcane	
India (Kharif)	March-December	Maize	
Australia	October-June	Maize	
Australia	April-December	Canola, Oats	
Australia	April-January	Wheat	
US	April-November	Maize	
US	Jan-December	Oats, Wheat, Sugarcane	
US	September-June	Canola	
US	April-October	Sunflower, Sugar beet	
US	May-October	Soybean	
Canada	May- November	Maize, Soybean	
Canada	May- October	Oats, Canola, Sunflower	
Canada	Jan- December	Wheat, Sugarcane	
Canada	April-September	Sugar beet	
Mexico	Jan-December	Maize, Sugarcane, Oats	
Mexico	September-July	Wheat	
Mexico	April-September	Sugar beet	
Mexico	November-June	Canola	
Mexico	April-December	Soybean, Sunflower	

Annex E – Climate risks' ranges

Climate risk definitions

Yield limiting factor	Definition
Heat stress	The number of days during the growing season that temperatures rise above the thermal limit for each crop type
Frost risk	The number of days during the growing season that conditions drop below freezing
Flood risk	The total amount of precipitation accumulated within a consecutive 5-day period during the growing season
Drought risk	Climate extreme index that accounts for both precipitation and evapotranspiration during the growing season

Baseline

Canola

Yield limiting factor	**Low risk**	**Moderate risk**	**High risk**	**Extremely high risk**
Heat stress	[-1,4]	[4,7]	[7,10]	[10,99]
Frost risk	[-1,70]	[70,160]	[160,230]	[230,365]
Flood risk	[-100,100]	[100,150]	[150,200]	[200,1000]
Drought risk	[0,15]	[15,19]	[19,23]	[23,1000]

Corn

Yield limiting factor	**Low risk**	**Moderate risk**	**High risk**	**Extremely high risk**
Heat stress	[-1,5]	[5,8]	[8,11]	[11,99]
Frost risk	[-1,30]	[30,80]	[80,130]	[130,365]
Flood risk	[-100,100]	[100,150]	[150,200]	[200,1000]
Drought risk	[0,15]	[15,18]	[18,21]	[21,1000]

Oats

Yield limiting factor	**Low risk**	**Moderate risk**	**High risk**	**Extremely high risk**
Heat stress	[-1,4]	[4,7]	[7,10]	[10,99]
Frost risk	[-1,80]	[80,170]	[170,240]	[240,365]
Flood risk	[-100,100]	[100,150]	[150,200]	[200,1000]
Drought risk	[0,15]	[15,18]	[18,21]	[21,1000]

Soybean

Yield limiting factor	**Low risk**	**Moderate risk**	**High risk**	**Extremely high risk**
Heat stress	[-1,5]	[5,8]	[8,11]	[11,99]
Frost risk	[-1,70]	[70,160]	[160,230]	[230,365]
Flood risk	[-100,100]	[100,150]	[150,200]	[200,1000]
Drought risk	[0,15]	[15,18]	[18,21]	[21,1000]

Sugar beet

Yield limiting factor	Low risk	Moderate risk	High risk	Extremely high risk
Heat stress	[-1,5]	[5,8]	[8,11]	[11,99]
Frost risk	[-1,80]	[80,170]	[170,240]	[240,365]
Flood risk	[-100,100]	[100,150]	[150,200]	[200,1000]
Drought risk	[0,15]	[15,18]	[18,21]	[21,1000]

Sugarcane

Yield limiting factor	Low risk	Moderate risk	High risk	Extremely high risk
Heat stress	[-1,6]	[6,9]	[9,12]	[12,99]
Frost risk	[-1,30]	[30,80]	[80,130]	[130,365]
Flood risk	[-100,100]	[100,150]	[150,200]	[200,1000]
Drought risk	[0,15]	[15,20]	[20,28]	[28,1000]

Sunflower

Yield limiting factor	Low risk	Moderate risk	High risk	Extremely high risk
Heat stress	[-1,6]	[6,9]	[9,12]	[12,99]
Frost risk	[-1,70]	[70,160]	[160,230]	[230,365]
Flood risk	[-100,100]	[100,150]	[150,200]	[200,1000]
Drought risk	[0,15]	[15,19]	[19,23]	[23,1000]

Wheat

Yield limiting factor	Low risk	Moderate risk	High risk	Extremely high risk
Heat stress	[-1,5]	[5,8]	[8,11]	[11,99]
Frost risk	[-1,70]	[70,160]	[160,230]	[230,365]
Flood risk	[-100,100]	[100,150]	[150,200]	[200,1000]
Drought risk	[0,15]	[15,19]	[19,23]	[23,1000]

Table grapes

Yield limiting factor	Low risk	Moderate risk	High risk	Extremely high risk
Heat stress	[-1,4]	[4,7]	[7,10]	[10,99]
Frost risk	[-1,70]	[70,160]	[160,230]	[230,365]
Flood risk	[-100,100]	[100,150]	[150,200]	[200,1000]
Drought risk	[0,15]	[15,18]	[18,21]	[21,1000]

Projections

Canola

Yield limiting factor	Extremely high yield gain	High yield gain	Moderate yield gain	No change	Moderate yield loss	High yield loss	Extremely high yield loss
Heat stress	NA	NA	NA	[-99,1]	[1,12]	[12,24]	[24,99]
Frost risk	[-1,99]	[-12,-1]	[-22,-12]	[-99,-22]	NA	NA	NA
Flood risk	NA	NA	NA	[-1000,50]	[50,150]	[150,250]	[250,1000]
Drought risk	NA	NA	NA	[-1000,1]	[1,2]	[2,3]	[3,1000]

Corn

Yield limiting factor	Extremely high yield gain	High yield gain	Moderate yield gain	No change	Moderate yield loss	High yield loss	Extremely high yield loss
Heat stress	NA	NA	NA	[-99,1]	[1,3]	[3,5]	[5,99]
Frost risk	[-1,99]	[-10,-1]	[-20,-10]	[-99,-20]	NA	NA	NA
Flood risk	NA	NA	NA	[-1000,50]	[50,150]	[150,250]	[250,1000]
Drought risk	NA	NA	NA	[-1000,0]	[0,1]	[1,2]	[2,1000]

Oats

Yield limiting factor	Extremely high yield gain	High yield gain	Moderate yield gain	No change	Moderate yield loss	High yield loss	Extremely high yield loss
Heat stress	NA	NA	NA	[-99,1]	[1,12]	[12,24]	[24,99]
Frost risk	[-1,99]	[-14,-1]	[-24,-14]	[-99,-24]	NA	NA	NA
Flood risk	NA	NA	NA	[-1000,50]	[50,150]	[150,250]	[250,1000]
Drought risk	NA	NA	NA	[-1000,0]	[0,1]	[1,2]	[2,1000]

Soybean

Yield limiting factor	Extremely high yield gain	High yield gain	Moderate yield gain	No change	Moderate yield loss	High yield loss	Extremely high yield loss
Heat stress	NA	NA	NA	[-99,1]	[1,3]	[3,5]	[5,99]
Frost risk	[-1,99]	[-12,-1]	[-22,-12]	[-99,-22]	NA	NA	NA
Flood risk	NA	NA	NA	[-1000,50]	[50,150]	[150,250]	[250,1000]
Drought risk	NA	NA	NA	[-1000,0]	[0,1]	[1,2]	[2,1000]

Sugar beet

Yield limiting factor	Extremely high yield gain	High yield gain	Moderate yield gain	No change	Moderate yield loss	High yield loss	Extremely high yield loss
Heat stress	NA	NA	NA	[-99,1]	[1,3]	[3,5]	[5,99]
Frost risk	[-1,99]	[-14,-1]	[-24,-14]	[-99,-24]	NA	NA	NA

Flood risk	NA	NA	NA	[-1000,50]	[50,150]	[150,250]	[250,1000]
Drought risk	NA	NA	NA	[-1000,0]	[0,1]	[1,2]	[2,1000]

Sugarcane

Yield limiting factor	**Extremely high yield gain**	**High yield gain**	**Moderate yield gain**	**No change**	**Moderate yield loss**	**High yield loss**	**Extremely high yield loss**
Heat stress	NA	NA	NA	[-99,1]	[1,5]	[5,7]	[7,99]
Frost risk	[-1,99]	[-10,-1]	[-20,-10]	[-99,-20]	NA	NA	NA
Flood risk	NA	NA	NA	[-1000,50]	[50,150]	[150,250]	[250,1000]
Drought risk	NA	NA	NA	[-1000,1]	[1,3]	[3,5]	[5,1000]

Sunflower

Yield limiting factor	**Extremely high yield gain**	**High yield gain**	**Moderate yield gain**	**No change**	**Moderate yield loss**	**High yield loss**	**Extremely high yield loss**
Heat stress	NA	NA	NA	[-99,1]	[1,5]	[5,7]	[7,99]
Frost risk	[-1,99]	[-12,-1]	[-22,-12]	[-99,-22]	NA	NA	NA
Flood risk	NA	NA	NA	[-1000,50]	[50,150]	[150,250]	[250,1000]
Drought risk	NA	NA	NA	[-1000,1]	[1,2]	[2,3]	[3,1000]

Wheat

Yield limiting factor	**Extremely high yield gain**	**High yield gain**	**Moderate yield gain**	**No change**	**Moderate yield loss**	**High yield loss**	**Extremely high yield loss**
Heat stress	NA	NA	NA	[-99,1]	[1,3]	[3,5]	[5,99]
Frost risk	[-1,99]	[-12,-1]	[-22,-12]	[-99,-22]	NA	NA	NA
Flood risk	NA	NA	NA	[-1000,50]	[50,150]	[150,250]	[250,1000]
Drought risk	NA	NA	NA	[-1000,1]	[1,2]	[2,3]	[3,1000]

Table grapes

Yield limiting factor	**Extremely high yield gain**	**High yield gain**	**Moderate yield gain**	**No change**	**Moderate yield loss**	**High yield loss**	**Extremely high yield loss**
Heat stress	NA	NA	NA	[-99,1]	[1,3]	[3,5]	[5,99]
Frost risk	[-1,99]	[-12,-1]	[-22,-12]	[-99,-22]	NA	NA	NA
Flood risk	NA	NA	NA	[-1000,50]	[50,150]	[150,250]	[250,1000]
Drought risk	NA	NA	NA	[-1000,0]	[0,1]	[1,2]	[2,1000]

Annex F – Climate impacts on supplier sourced crops' performance

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