Climate change impacts on maize and dry bean yields of smallholder farmers in Honduras

Impacto del cambio climático sobre el rendimiento de maíz y frijol de los pequeños productores de Honduras

Carlos G. H. DÍAZ-AMBRONA
Universidad Politécnica de Madrid, España
Corresponding autor
carlosgregorio.hernandez@upm.es

Rubén GIGENA
Escuela Agrícola Panamericana Zamorano, Honduras

Carlos O. MENDOZA
Escuela Agrícola Panamericana Zamorano, Honduras

Climate change impacts
on maize and dry bean yields of smallholder farmers in Honduras

Impacto del cambio climático sobre el rendimiento de maíz y frijol de los pequeños productores de Honduras

Carlos G. H. DÍAZ-AMBRONA
Universidad Politécnica de Madrid, España
Corresponding autor
carlosgregorio.hernandez@upm.es

Rubén GIGENA
Escuela Agrícola Panamericana Zamorano,
Honduras

Carlos O. MENDOZA
Escuela Agrícola Panamericana Zamorano,
Honduras

Abstract

The rotation maize and dry bean provides the main food supply of smallholder farmers in Honduras. Crop model assessment of climate change impacts (2070–2099 compared to a 1961–1990 baseline) on a maize–dry bean rotation for several sites across a range of climatic zones and elevations in Honduras. Low productivity systems, together with an uncertain future climate, pose a high level of risk for food security. The cropping systems simulation dynamic model CropSyst was calibrated and validated upon field trail site at Zamorano, then run with baseline and future climate scenarios based upon general circulation models (GCM) and the ClimGen synthetic daily weather generator. Results indicate large uncertainty in crop production from various GCM simulations and future emissions scenarios, but generally reduced yields at low elevations by 0 % to 22 % in suitable areas for crop production and increased yield at the cooler, on the hillsides, where farming needs to reduce soil erosion with conservation techniques. Further studies are needed to investigate strategies to reduce impacts and to explore adaptation tactics.

Keywords: Central America, Crop Simulation model, CropSyst, Food security, Subsistence, Subtropical.

Resumen

La rotación maíz–frijol es la fuente de alimentos de los pequeños productores de Honduras. Se ha determinado el impacto del cambio climático (comparado 2070–2099 con 1961–1990) mediante un modelo de simulación de la rotación en localidades de Honduras de distintas zonas climáticas y altitudes. La baja productividad, unida a las incertidumbres sobre el clima futuro, genera un elevado riesgo sobre la seguridad alimentaria. El modelo de simulación de sistemas de cultivo CropSyst se ha calibrado y validado con datos de campo del Zamorano, después se ha aplicado al clima base y a los escenarios futuros de varias simulaciones de GCMs y escenarios de emisión, aplicando el generador de datos diarios ClimGen. Los resultados indican una gran incertidumbre, pero, en general, una reducción del rendimiento del 0 % al 22 % en las zonas bajas, más adecuadas para el cultivo y un aumento en las zonas más frías, en zonas montañosas donde la agricultura debe evitar la erosión mediante la aplicación de técnicas de conservación del suelo. Futuros estudios son necesarios para investigar cómo reducir el impacto y buscar estrategias de adaptación en las prácticas agrícolas.

Palabras clave: América central, modelo de simulación de cultivo, CropSyst, seguridad alimentaria, subsistencia, subtropical.

1
Introduction

Smallholder farmers of Honduras use traditional agricultural management for the popular rotation maize (*Zea mays* L.) and dry or common bean (*Phaseolus vulgaris* L.). These grains are consumed every day in 98 % of the households (Hintze et al 2003). The main growing period of maize is from May to October as summer monocrop, and represents 75 % of annual maize production (Barreto and Hartkamp 1999). From 1993 to 2003, average maize yields range from 1 to 2 t ha^{-1}, with a country average of 1.407±0.108 t ha^{-1}, and dry bean was 0.640±0.076 t ha^{-1}. Since 1970, food production *per capita* has decreased due to an increase in population by 300 %, maize yield increased less than 40 % in the last 35 years, yearly rate of 10 kg ha^{-1}, while bean productivity increased only 15 %, yearly rate of 2 kg ha^{-1} (FAO 2011). Arable land is 3.1 million hectares, 28.2 % of the country. Hillsides cover the 80 % of the country and have lower agricultural potential (Jansen et al 2006).

Impacts of climate change need to be assessed at household level, so that small farmers who depend on agriculture for survival can be properly targeted in research and development activities for poverty alleviation (Jones and Thornton 2003). Low productivity systems, together with an uncertain future climate, pose a high level of risk for food security in this country. General circulation models (GCMs) are numerical models that provide scenarios of climate change in areas without nested regional circulations models (RCMs) (Mearns et al 2001; Mearns et al 2003). GCM outputs are extracted at a monthly time scale and differences between modelled present–day and future climate are added to observed weather data to obtain future monthly data. Synthetic daily climate series can then be produced for current and future climates using weather generators based on statistical descriptions (Barrow et al 1996; Semenov et al 1998).

The objective was to study the first order impact on traditional farming systems of grain maize and common bean rotation. Steps to achieve this objective were: (i) calibrate and validate the CropSyst model under dry subtropical environment for the traditional cropping systems, and (ii) explore the impact of climate change on the basic grain supply system.

2
Material and Methods

Crop simulation model had been used as transfer function of climate variability to crop yield (Reilly 1996). The generic model CropSyst (Stöckle et al 2003) can be used where crop information is scarce. This model had been used successfully to assess impact of climate change and climate

CLIMATE CHANGE IMPACTS ON MAIZE AND DRY BEAN YIELDS… Carlos G. H. Díaz-Ambrona, Rubén Gigena y Carlos O. Mendoza
Revista Iberoamericana de Estudios de Desarrollo / Iberoamerican Journal of Development Studies
**6_** Volumen/volume 2, número/issue 1 (2013), pp. 4-22. ISSN: 2254-2035

variability on the yield of various crops (Parry et al 1999; Iglesias et al 2000; Bellocchi et al 2002; Parry et al 2004; Scott et al 2004; Mínguez et al 2007).

2.1. Field experiments

Data from field experiments of maize and dry bean were used to calibrate and validate CropSyst. Field experiments were conducted from 1998–2002 at Zamorano in the Yegüare Valley, Central Honduras (Latitude 14°00'45"N, Longitude 87°00'79"W, Elevation 780 masl). We used five maize cultivars (Guayape, Cargill C–343, HB–104, DeKalb B–338, H–27), including hybrids and open pollinated types, to run the model. The 12 cultivars of common red bean included in the experiment were: RAB–50, RAB–20, RAB–205, Desarrural, Desarrural gene I, Cuarenteño Brillante, Zamorano, Danlí 46, UW22–34, Dorado, Honduras43–40 and Tío Canela 75.

2.2. Observed weather data

There are few reliable long time weather series for Honduras. Most of the accessible data are monthly precipitation and temperature. We evaluated original monthly data from 14 stations provided from *Fundación Hondureña de Investigación Agrícola* (Paz and Mata 1999) and from Zamorano and selected the most representative and complete ones (figure 1 and table 1). The locations selected were representative of
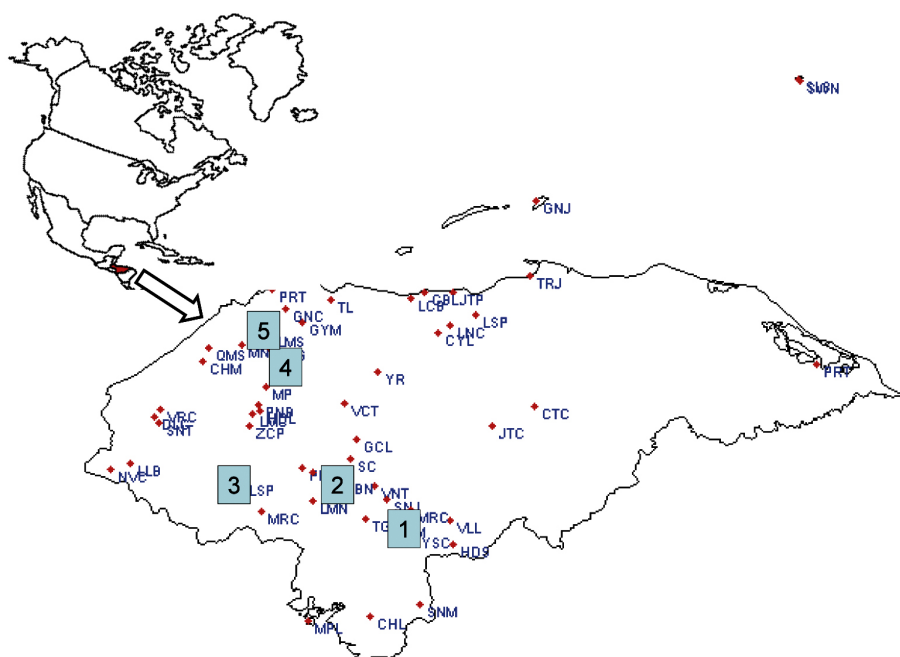
Figure 1
Location and weather station in Honduras: 1, Zamorano; 2, Comayagua; 3, La Esperanza; 4, La Lima 5, Valle de Sula. Red points are weather stations with monthly data available at METART from FAO.

CLIMATE CHANGE IMPACTS ON MAIZE AND DRY BEAN YIELDS… Carlos G. H. Díaz-Ambrona, Rubén Gigena y Carlos O. Mendoza
Revista Iberoamericana de Estudios de Desarrollo / Iberoamerican Journal of Development Studies
Volumen/volume 2, número/issue 1 (2013), pp. 4-22. ISSN: 2254-2035   _7

	Valle de Sula	La Lima	Comayagua	Zamorano	La Esperanza
Mean air temperature ºC					
January	24.8	23.6	22.6	22.5	14.2
February	25.1	24.5	23.9	23.4	14.7
March	26.0	25.8	25.4	25.2	15.5
April	26.6	27.2	26.7	27.0	17.4
May	27.3	27.1	26.4	26.4	17.7
June	26.7	27.0	25.3	25.1	17.9
July	26.7	26.4	25.2	24.4	17.4
August	26.8	26.7	25.0	24.7	17.3
September	26.7	26.4	24.4	24.6	16.8
October	25.8	25.5	24.2	24.2	16.1
November	25.1	24.4	23.1	23.2	15.4
December	24.4	23.4	22.2	22.6	14.3
ANNUAL	26.1	25.0	20.8	24.4	16.2
Precipitation mm					
January	163	59	8	8	7
February	110	38	1	7	5
March	120	46	5	12	12
April	60	35	24	42	76
May	61	59	75	150	140
June	90	135	112	150	286
July	162	99	84	129	129
August	201	113	103	160	184
September	194	150	154	202	252
October	303	108	54	120	46
November	419	164	38	43	46
December	222	94	135	17	18
ANNUAL	1991	987	541	1039	1297

Table 1
Temperature and precipitation regimes: Monthly and annual mean values correspond to observed weather data (Honduras).

different elevation, temperatures and precipitation regimes. The five locations were Valle de Sula (Latitude N 15º 44' 11", longitude W 87º 49' 15", 10 masl, from 1986 to 1998), La Lima (Latitude 15º 25' 36", longitude W 87º 56' 07", 30 masl, from 1987 to 1998), Comayagua (Latitude 14º 24' 18", longitude W 87º 39' 40", 579 masl, from 1995 to 1998), Zamorano (Latitude 14º 00' 45" N, longitude W 87º 00' 79", 780 masl, from 1945 to 2003) and La Esperanza (Latitude 14º 18' 45", longitude W 88º 18' 17", 1680 masl, from 1986 to 1998). Monthly average and standard deviation was calculated for rainfall, rain days, relative humidity, solar radiation, average, maximum and minimum temperatures.

2.3. Synthetic base climate

ClimGen weather generator software version 4.1.05 (Stöckle et al 1999; 2001) was used to generate synthetic daily weather series from monthly data followed Donatelli et al (2002). ClimGen has been tested in many different locations (Villalobos et al 1999; Castellvi and Stöckle 2001; Jovanovic et al 2003). ClimGen uses the normal distribution to generate daily maximum and minimum temperature values. ClimGen generates precipitation, daily maximum and minimum temperature, solar radiation, air humidity, and wind speed. All generation parameters are calculated for each site of interest with enough information to parameterize the generator equations. ClimGen input were, average and standard deviation of monthly data for each location. Fraction of rainy days was calculated from observed rainy days (or data). Average and standard deviation of maximum and minimum temperatures were also introduced manually for each location. Obtained synthetic daily weather data was compared with monthly observed data.

2.4. Climate change scenarios

MAGICC software (Version 4.1, September 2003) was used to generate climate change data by the IPCC (Intergovernmental Panel on Climate Change) Third Assessment Report (Hulme et al 2000; Wigley et al 2002; Wigley 2003). Four global climate models were used to formulate the future climate projection and to reduce uncertainties through the use of an ensemble of projection (Ruiz–Ramos and Mínguez 2010). They differ on spatial resolution, in scenarios availability and ability to represent current climate. Models from GFDL (Geophysical Fluids Dynamics Lab), GISS (Goddard Institute for Space Studies) and UKMO (from Hadley Centre for Climate Prediction and Research at the United Kingdom Meteorological Office), in this last case the results of two versions HAD295 and HAD300 were used. Six Emissions Scenarios (SRES 2000) A2 and B2 were derived from GCM runs (IPCC–TGCIA 1999). The A2 family scenario is based on population projection of 15.1 billion by 2100 and to 635–856 ppm CO_2 and the B2 family scenario is based on population projection of 10.4 billion by 2100 and corresponds to 500–600 ppm CO_2 from 2070–2100 future greenhouse gas emissions (IPCC, 2000). For each family we choose three scenarios the «central», or «best–guess», the minimum and the maximum temperature. Four GCMs, two families and three scenarios give 24 combinations to assessment of impacts. Honduras is a small country covered by one grid in the CGM, the surrounding grids have more sea than land. Also, the scarcity of weather stations is another limitation for this study. Application like MarkSim (Jones and Thornton 2000) for observed weather interpolation does not work in Honduras.

From all climate models, extreme values were taken to cover all extreme possibilities (fig. 2). For the A2 family the highest value of temperature was the HAD300, and lowest the GFDL90. For the B2 family,

CLIMATE CHANGE IMPACTS ON MAIZE AND DRY BEAN YIELDS... Carlos G. H. Díaz-Ambrona, Rubén Gigena y Carlos O. Mendoza
Revista Iberoamericana de Estudios de Desarrollo / Iberoamerican Journal of Development Studies
Volumen/volume 2, número/issue 1 (2013), pp. 4-22. ISSN: 2254-2035   _9

the highest value of temperature was the HAD295 and the lowest value was provided by the GFDL90. In the case of the precipitation, the HAD300 for the case of greater change in the A2 family is used and the GISS95 for the level gives low change. In the same way, the HAD300 for the highest value of the B2 family and the HAD295 for the lowest value was used. The atmospheric CO_2 concentrations were taken as the estimates used in the climate modelling experiments, which on average were 333 ppm for the 1961–1990 baseline, and 718 ppm and 566 ppm for 2071–2100 for the A2 and B2 scenarios respectively.
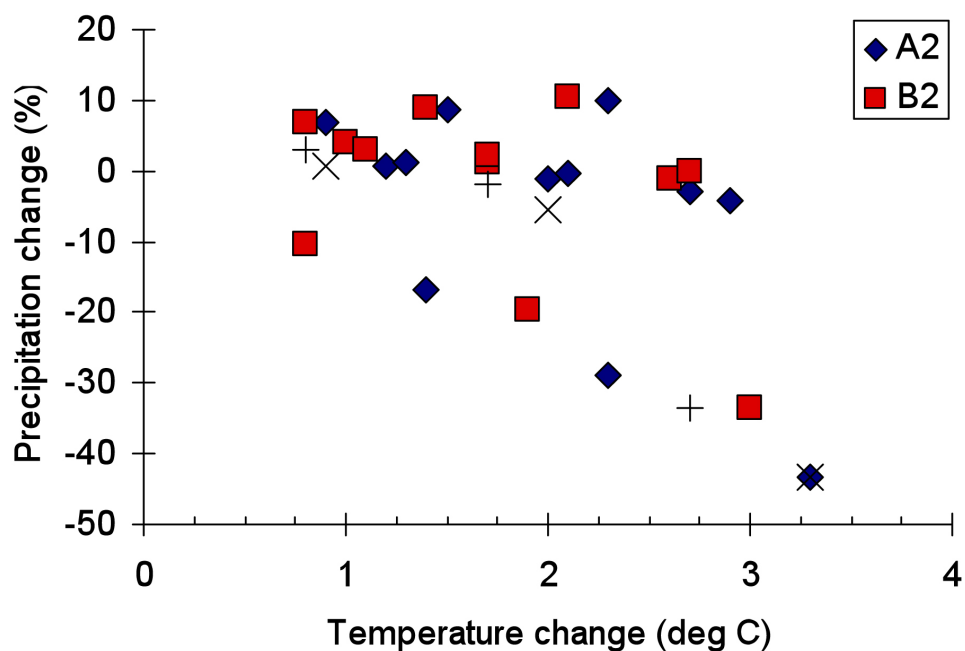
Figure 2

Changes in average annual temperature and precipitation percentage for the 2070–2099 relative to 1961–1990 from 24 combinations of different Global Climate Models and scenarios SRES A2 and B2 for Honduras grid from MAGICC SCENGEN software. The average chosen scenarios low, medium and high changes for A2 (×) and B2 (+).

2.5. Downscaling technique

The downscaling technique was based on the application over the observed weather monthly data the average output of a combination of different global circulation model (GCM) and climate scenarios A2 and B2. This is the standard delta method, where the observed baseline data are adjusted for the mean monthly differences (for temperatures) or ratios (for precipitation) between climate model outputs for future and control climates. Relative changes in the outputs of the climate models were applied to meteorological observed monthly data (table 2). Then those data were introduced to ClimGen considering no change on standard deviation to obtained daily series for 2070–2099 that were used as inputs for crop model.

CLIMATE CHANGE IMPACTS ON MAIZE AND DRY BEAN YIELDS... Carlos G. H. Díaz-Ambrona, Rubén Gigena y Carlos O. Mendoza
Revista Iberoamericana de Estudios de Desarrollo / Iberoamerican Journal of Development Studies
10_ Volumen/volume 2, número/issue 1 (2013), pp. 4-22. ISSN: 2254-2035

| Month | Scenario | | | | | |
| | A2 | | | B2 | | |
	High	Medium	Low	High	Medium	Low
Projected increases in mean air temperature ºC						
January	2.6	1.8	1.1	2.5	1.6	1.0
February	2.9	1.8	1.1	2.4	1.6	1.0
March	2.7	2.0	1.3	2.6	1.7	1.1
April	3.0	2.1	1.3	2.6	1.7	1.0
May	3.4	2.3	1.4	2.9	1.9	1.1
June	3.3	2.3	1.4	2.8	1.8	1.1
July	3.0	2.3	1.4	2.4	1.9	1.1
August	3.0	2.1	1.3	2.7	1.8	1.1
September	2.8	1.9	1.1	2.6	1.7	1.0
October	2.7	1.9	1.1	2.5	1.7	0.9
November	2.5	1.7	1.0	2.2	1.4	0.9
December	2.4	1.5	0.9	2.2	1.5	0.9
ANNUAL	2.9	2.0	1.2	2.5	1.7	1.0
Projected changes in mean cumulative precipitation %						
January	47	47	39	10	9	7
February	34	35	30	14	14	12
March	27	25	20	6	4	3
April	6	13	7	13	14	12
May	–6	0	3	–3	2	4
June	–7	–4	–2	–1	5	5
July	–20	–5	–9	–14	–8	–5
August	–24	–15	–9	–19	–11	–6
September	–20	–10	–3	–22	–6	–6
October	–10	–9	–7	–8	–6	–5
November	30	24	17	8	21	14
December	–15	–9	–4	–1	4	4

Table 2
Climate change scenarios for Honduras as projected changes between baseline (1961-1990) and future climate (2070–2099) for differing trajectories SRES (Special Report on Emissions Scenarios) marker scenarios A2 and B2 projected a CO_2 concentration of concentration of 718 ppmv and 566 ppmv at 2070–2099 period.

2.6. Cropping system simulation model

The cropping systems simulation model, acronym CropSyst (Stöckle and Nelson 2001; Stockle et al 2003) version 3.03.16 (Jan 20, 2003) was used. CropSyst includes modules dealing with plant phenology, growth, and yield, together with dynamics of nitrogen in crops and soils and soil water balance. Plant phenology development is driven by temperature and photoperiod. This model takes into account the effect of light, water, nitrogen, and CO_2 on crop growth. The model uses the radiation and

CLIMATE CHANGE IMPACTS ON MAIZE AND DRY BEAN YIELDS… Carlos G. H. Díaz-Ambrona, Rubén Gigena y Carlos O. Mendoza
Revista Iberoamericana de Estudios de Desarrollo / Iberoamerican Journal of Development Studies
Volumen/volume 2, número/issue 1 (2013), pp. 4-22. ISSN: 2254-2035 _11

transpiration–use efficiency concepts to calculate daily biomass (Monteith 1977; Tanner and Sinclair 1983). Grain yield is calculated from total biomass accumulation during the crop season using the harvest index approach that is responsive to water stress. CropSyst does not simulate the effect of weeds, diseases nor pest. Crop response to elevated CO_2 in CropSyst is considered a lineal positive effect (Tubiello et al 2000; Donatelli et al 2002).

For this study we used current cultivars and cultural practices for medium production technology. We used generic cultivars for maize (Batres 1988; Auhing 1989; Fuentes 1991; Villaseca 2001; Rubio 2002) and common bean (Guerrero 1988; Robleto 1988; Haro 1998) for CropSyst crop parameter (table 3). Root mean squared error (RMSE) and modeling efficiency were calculated (Loague and Green 1991).

Parameter	Unit	Maize	Common bean
Base temperature	ºC	10	3
Cut–off temperature	ºC	30	22
Optimum mean daily temperature for growth	ºC	20	20
Emergence	ºC day	117	100
Leaf duration degree–days	ºC day	600	700
Begin flowering	ºC day	898	1000
Peak leaf area index (LAI)	ºC day	800	1040
Begin grain filling	ºC day	1211	1020
Physiological maturity	ºC day	1669	1500
Maximum rooting depth	m	0.80	1.50
Maximum water uptake	mm/day	14	10
Maximum expected LAI	m2/m2	5	5
Stem/leaf partition coefficient	dimensionless	2.80	3.00
Evapotranspiration crop coefficient at full canopy	dimensionless	1.10	1.00
Above ground biomass–transpiration coefficient	kg kPa /m² m	7.50	5.75
Light to above ground biomass conversion	g/MJ day	3.00	2.00
Actual to potential transpiration ratio that limits leaf area growth	ratio	0.95	0.80
Actual to potential transpiration ratio that limits root growth	ratio	0.50	0.50
Leaf water potential at the onset of stomatal closure	J/kg	–1200	–700
Wilting leaf water potential	J/kg	–1800	–1600
Extinction coefficient for solar radiation	dimensionless	0.50	0.50
Unstressed harvest index	ratio	0.43	0.50
Nitrogen uptake adjustment	dimensionless	1	1
Nitrogen availability adjustment	dimensionless	1	1
Maximum N concentration during early growth	kgN/kg biomass	0.040	0.050
Minimum N concentration at maturity	kgN/kg biomass	0.007	0.007
Maximum N concentration at maturity	kgN/kg biomass	0.014	0.020
Ratio of growth at elevated reference ppm to baseline ppm atmospheric CO_2 concentration	ratio	1.08	1.25
Elevated reference atmospheric CO_2 concentration	ppm	750	750
Baseline reference atmospheric CO_2 concentration	ppm	350	350

Table 3
Calibrate parameters for cropping systems dynamic model CropSyst for a reference cultivar of maize and common bean for Honduras.

CLIMATE CHANGE IMPACTS ON MAIZE AND DRY BEAN YIELDS… Carlos G. H. Díaz-Ambrona, Rubén Gigena y Carlos O. Mendoza
Revista Iberoamericana de Estudios de Desarrollo / Iberoamerican Journal of Development Studies
12_ Volumen/volume 2, número/issue 1 (2013), pp. 4-22. ISSN: 2254-2035

Baseline and climate change scenarios were input into CropSyst. The model was run for each location with the same crop management and cultivar. As traditional farming did not change we considered to maintain this management in future scenarios. Simulation was made under rainfed conditions of the rotation maize–dry bean. Maize crop management comprised one tillage operations (field cultivator) before planting, sowing on May 2nd, and two nitrogen fertilizer applications for a total of 50 kg N/ha (30 kg N/ha at sowing and 25 days after sowing 20 kg N/ha). The maize stubble was burned, after tillage operations (field cultivator) for soil preparation, dry bean was sowed on September 16th. Dry bean was fertilized with two nitrogen applications for a total of 42 kg N/ha (12 kg N/ha at sowing and 30 days after sowing 30 kg N/ha). We chose the typical soils for each location (table 4) (FAO 1995; Castro 2003; Fernández 2003).

Location	Elevation	Soil depth	pH	Hydrologic condition	Texture			Soil total nitrogen	Soil organic matter
					Sand %	Clay %	Silt %		
	masl	m						m	%
Valle de Sula	10	1.20	7.35	Good	25	35	40	0.13	2.68
La Lima	30	1.20	6.97	Good	30	30	40	0.14	2.88
Comayagua	565	1.20	6.29	Fair	35	25	40	0.12	2.17
Zamorano	800	1.20	5.61	Fair	40	27	33	1.82	2.82
La Esperanza	1680	1.25	5.26	Fair	25	35	40	0.11	2.22

Table 4
Representative soil type main properties entries for cropping systems dynamic model CropSyst simulation for different locations in Honduras.

3
Results

Results indicate large uncertainty in crop production from various GCM simulations and future emission scenarios, but generally reduced yields at low elevations by 0 % to 22 % and increased yields at the cooler, elevated sites. Low productivity systems, together with an uncertain future climate, pose a high level of risk for food security.

3.1. Crop model performance

Crop phenology is a good indicator of crop development and growth. Phenology depends on temperature and day length. Observed maize maturity ranged from 120 to 125 days after sowing. For all maize varieties the RMSE for emergence was 0.5 days and for flowering and maturity were 2.0 and 9.0 days respectively. All maize yields ranged from 0.6 to 6.5 t/ha, RMSE = 1.2 t/ha. Maize open lines measured average yield in Zamorano was 1.6 t/ha and standard deviation of 0.256 t/ha. Maize hybrid cultivar measured average yield in Zamorano was 3.4 t/ha and standard deviation of 1.17 t/ha. The simulation of maize grain yields ranged from 1.5 to 3.7 t/ha

CLIMATE CHANGE IMPACTS ON MAIZE AND DRY BEAN YIELDS... Carlos G. H. Díaz-Ambrona, Rubén Gigena y Carlos O. Mendoza
Revista Iberoamericana de Estudios de Desarrollo / Iberoamerican Journal of Development Studies
Volumen/volume 2, número/issue 1 (2013), pp. 4-22. ISSN: 2254-2035 _**13**

(RMSE = 0.786 t/ha, and modelling efficiency of –0.48). Regression relation of measured and simulated (line 1:1) of grain yield in maize and common bean (figure 3) showed a better model performance of common bean than maize. Observed common bean yield ranged from 0.86 to 2.2 t/ha. Observed crop maturity ranged from 70 (cultivar Desarrural) to 82 (cultivar UW 22–34) days after sowing common bean secondary season crop (growing period during the dry season) showed a 1.29 t/ha and standard deviation of 0.36 t/ha, and for sowing as main crop (during the wet season) yield increased to 1.73 t/ha and standard deviation of 0.34 t/ha (figure 3). Common bean yield simulation was better than maize. The CropSyst model provided good estimates of common bean (r^2 = 0.81, root mean squared error of 0.342 t/ha and modelling efficiency of 0.59).
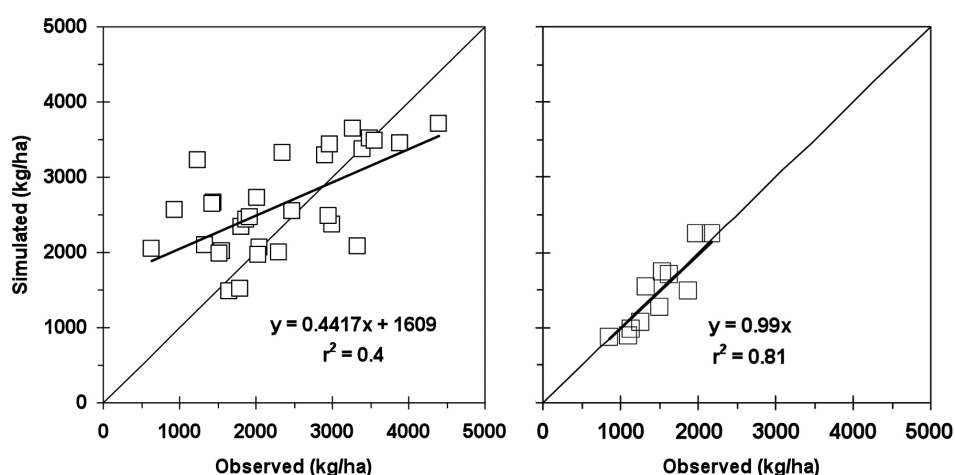
Figure 3
Observed versus simulated yield with cropping systems dynamic model CropSyst in Honduras for maize and common bean.

3.2. Baseline climate

Climate in Valle de Sula and La Lima, in the northern coast, shows a wet tropical climate, warm temperatures (26.1 °C and 25 °C average annual temperature respectively) and high rainfall (1991 mm and 987 mm average annual precipitation respectively).

Comayagua has dry tropical weather with the lowest annual precipitation (541 mm) and high variabillity, annual mean temperature is 20.8 °C. Zamorano is dry tropical, with a strong dry season and high precipitation variability during the rainy seasons, annual precipitation is 1039 mm and mean temperature is 24.4 °C. Long series of data for monthly rainfall recorded at Zamorano showed short and constant cycles of dry and wet periods. The coldest site is La Esperanza (mean annual temperature of 16.2 °C), it is the highest weather station located in the central mountains of the country, and it has a temperate climate with annual precipitation of 1297 mm.

CLIMATE CHANGE IMPACTS ON MAIZE AND DRY BEAN YIELDS… Carlos G. H. Díaz-Ambrona, Rubén Gigena y Carlos O. Mendoza
Revista Iberoamericana de Estudios de Desarrollo / Iberoamerican Journal of Development Studies
14_ Volumen/volume 2, número/issue 1 (2013), pp. 4-22. ISSN: 2254-2035

3.3. Climate change scenarios and crop production

For Zamorano annual mean temperatures change from observed data of 2.8 °C in scenario A2 high to –0.1 °C in B2 low by 2070-2100 period. For the other locations, changes were related with projections from 2.9 °C to 1 °C. The change on precipitation regimes was low among all locations. The higher decrease was 13.2 % of annual rainfall in La Esperanza and similarly in Comayagua. In these locations precipitation reduction occurs in all scenarios. In Valle de Sula, the wettest area, there was not variations in rainfall (from +6.7 % to –1.4 % of annual 2145 mm).

Temperature increase had a direct effect over crop phenology. In all scenarios and locations, crop growth period, from sowing to crop maturity, showed a reduction due to warmer temperatures. Earlier crop flowering and maturity reduced potential yield. Maize maturity was reached 17 days earlier in Zamorano and 11 days earlier in Comayagua and la Esperanza. For common bean current crop periods is 63 to 83 days after sowing, respectively, going from warmer to cooler locations. Future scenarios showed reduction of 3 to 20 days from sowing to crop maturity.

Our results showed a slight impact on maize yield similar to Jones and Thornton (2003). Future climate change increased yield variability (figure 4). In Zamorano crop simulation under current weather data series
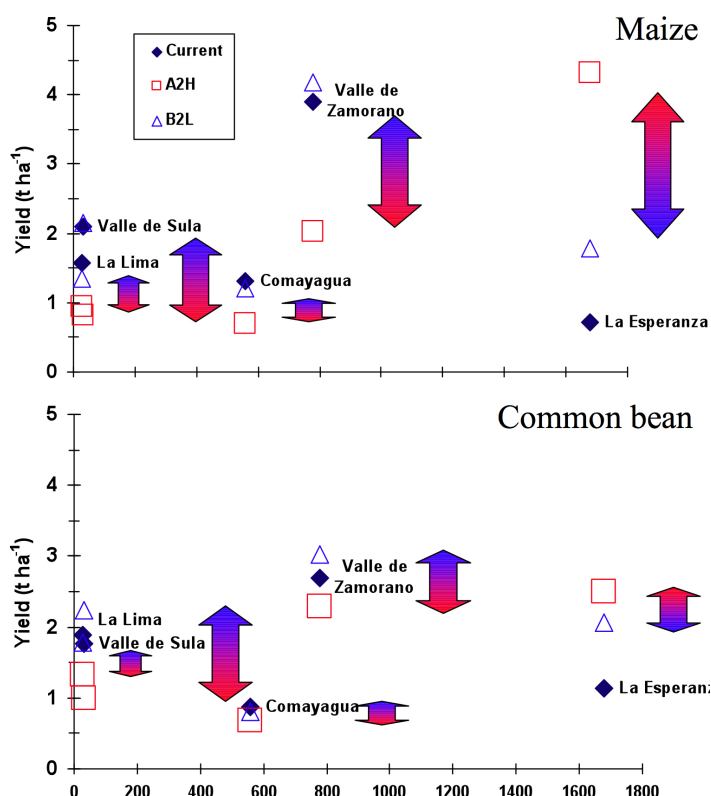
Figure 4

Simulated maize and common bean average yields for different location and scenarios for current and extremes SRES marker scenarios A2 and B2 projected a CO_2 concentration of 718 ppmv and 566 ppmv at 2070-2099 period, respectively arrow shows yield range between scenarios.

CLIMATE CHANGE IMPACTS ON MAIZE AND DRY BEAN YIELDS... Carlos G. H. Díaz-Ambrona, Rubén Gigena y Carlos O. Mendoza
Revista Iberoamericana de Estudios de Desarrollo / Iberoamerican Journal of Development Studies
Volumen/volume 2, número/issue 1 (2013), pp. 4-22. ISSN: 2254-2035   _15

showed maize yield of 3.9 t/ha and common bean of 2.7 t/ha. Crop yield under future climate scenarios was variable showing high uncertainties. From the extreme scenario A2 high, maize yield dropped to 2.03 t/ha, that represents 48 % decrease of present yield, but increased to 4.17 t/ha under B2 high scenario, a 7 % increase over present yields. Common bean yield ranged from 1.83 t/ha, that represents 32 % decrease, to 3.44 t/ha (28 % increase) respectively to B2 high to A2 low. Taking into account the intensive rotation maize–common beans, simulations showed an inverse relation between maize and common bean yields. Higher yield of maize reduced the yield in the following common bean.

Comayagua is the driest location of this study and all scenarios reduced rainfall. Crop simulation under current climate showed an average yield of 1.32 t/ha and 0.88 t/ha for maize and common bean respectively. Future climate produced a slow increase in yield of maize (4 %) and common bean (6 %) obtained under B2 high scenario and strong decrease in maize (53 %), yield dropped to 0.7 t/ha, and in common bean (22 %) dropped to 0.69 t/ha, respectively for A2 medium and A2 high scenario.

The northern locations, Valle de Sula and La Lima, showed similar behaviour (figure 4). In the Valley of Sula current simulated maize yield was 2.09 t/ha. Maize yield increased only under B2 low scenario in which yield was 2.15 t/ha (3 % increase). The A2 high scenario maize yield was the lowest result with 0.83 t/ha (61 % decrease). The common bean yields in the Valley of Sula increased in all the cases, except in A2 high (0.99 t/ha, 44 % decrease), exceeding the present average of 1.76 t/ha. The greater production of yield was the A2 Low with 2.34 t/ha (33 % increase).

For La Lima there were not future scenarios better than the current maize yields. All future scenarios showed a yields reduction. The current climate had a yield of 1.58 t/ha, followed by the A2 Low scenario with 1.41 t/ha (11 % decrease) and the lowest yields were A2 and B2 high with 0.94 and 0.91 t/ha, respectively (41 % and 42 % decrease). Common bean yield in La Lima were similar behaviour than maize. The current yield was the highest with 1.88 t/ha. The highest yield of future scenarios (A2 low) was the 94 % of current yield (6 % decrease), it was 1.86 t/ha, and the smaller yield was the B2 high with 1.26 t/ha (33 % decrease).

La Esperanza is the coldest area in Honduras. We run two simulations to take into account different maize growth response to optimal temperature. One of them with a condition of 10 ºC crop optimum temperature required to cultivate and the second simulation was with the same cultivar used in the other locations; with a crop optimal growth temperature of 20 ºC (current cultivar). In the first case, the current climate showed a maize yield of 0.71 t/ha (production of biomass of 9.17 t/ha). In all future climate scenarios yield was increased from a range of 2.82 t/ha to 4.32 t/ha. Performance of simulated maize development was better in the warmer scenarios than with current low temperatures. In this case,

CLIMATE CHANGE IMPACTS ON MAIZE AND DRY BEAN YIELDS... Carlos G. H. Díaz-Ambrona, Rubén Gigena y Carlos O. Mendoza
Revista Iberoamericana de Estudios de Desarrollo / Iberoamerican Journal of Development Studies
16_ Volumen/volume 2, número/issue 1 (2013), pp. 4-22. ISSN: 2254-2035

the average of simulted yield for maize was 4.32 t/ha (increased 25 % in biomass of 11.45 t/ha) in the A2 high scenario and the B2 lower scenario had the smaller yield 1.78 t/ha. In the second case, there was no yield for the present climate since the condition optimal growth temperature of 20 ºC was too restrictive. Nevertheless, in the A2 low was the minimum yield of 2.51 t/ha and the one of highest yield was the B2 low with 3.59 t/ha. Again, two cases for this locality were formulated for common bean, like for maize, a 10 ºC optimal growth temperature and 20 ºC degrees in another one. For the case of 10 °C, all scenarios were over the present average of 1.14 t/ha. The maximum yield occurred in the A2 medium scenario with 2.53 t/ha (108 % increase) and the minimum 1.81 t/ha (46 % increase) on B2 high scenario. With the optimal growth temperature of 20 °C, the restriction was too severe in the present scenario, thus there was no emergence of the crop. The warmer scenarios showed better temperature conditions for maize development, the maximum maize yield was 3.37 t/ha in the A2 high scenario and the minimum yield was 2.72 t/ha on the B2 high scenario.

4
Discussion and conclusion

The long term rainfall series from Zamorano in central Honduras showed a relatively constant subtropical dry–wet climate. We have extended the evaluation and application of CropSyst to a subtropical environment in maize smallholder production systems. The performance of the model in this region was comparable to obtained in other environments and other crop models in similar conditions. The accuracy of model predictions varied considerably with the maize variety examined and may need further development. Our study showed that the increases in temperature and low reduction in precipitation from different climate scenarios lead to reduce yields for both crops. Warmer temperatures reduce the length of the growing season. Maize and common bean yields decreased in all location under warmer scenario A2 high, except in mountain areas, where current yields are limited by cooler temperatures. Maize yield shows a higher impact, future yield range from 40 % to 110 % of current yields compared with common bean range from 60 % to 130 % in median and lower zones. In both cases future climate increased yield uncertainty and maximum and minimum records were diminished (figure 4). Impact of climate change is higher in maize than in common beans. We found better growing conditions under climate change in highlands, mountain areas were represented in our study by La Esperanza (1680 masl). Arable land availability in this mountain region is scarce and there is not possibility to increase crop production in a climate change scenario. This result is according with Jones and Thornton (2003) report in the Ethiopian highlands plateau.

CLIMATE CHANGE IMPACTS ON MAIZE AND DRY BEAN YIELDS… Carlos G. H. Díaz-Ambrona, Rubén Gigena y Carlos O. Mendoza
Revista Iberoamericana de Estudios de Desarrollo / Iberoamerican Journal of Development Studies
Volumen/volume 2, número/issue 1 (2013), pp. 4-22. ISSN: 2254-2035 _17

The predicted impacts of climate change on maize yield (39 % to 107 % of current yield) and common bean yield (56 % to 133 % of current yield) may add other critical factor in meeting to the challenge of ensuring food security. Crop production in different future climate scenarios showed a high uncertainty, but for current maize varieties the first order impact is to reduce yields close to 25 %. Common bean did not show a clear trend for some scenarios and locations reduction could be affecting to half of the current yield, while in others increased productivity. In our simulation common bean has been cultivated as second crop, during the dry season. Recommendations to reduce climate change impact are: (i) Smallholder will need to use appropriate cultivars adapted to warmer temperatures. Smallholders crop white maize for food and yellow maize for feed in both cases are mainly open lines. Since their maize–common bean farming system is based on two sowing periods with different growing conditions and locations, smallholder need to characterize their varieties according to different current climate to ensure genetic material better adapted to future climate surveying their agro biodiversity. (ii) Improve soil and water conservation techniques in hillside farming systems. (iii) Agroforestry could be help to reduce supra optimal temperatures in field crops. Current agronomic practices and cultivar should be adapted to increase productivity in order to cope with climate scenarios. Honduras population and basic grain demand increases quickly. Higher temperatures are the main impact of these different climate scenarios, because precipitation change is low. New varieties for warmer environment must be tested.

There are some factors that reduce the reliability of GCMs in Honduras, these are: (i) critical geographic location in terms of climatic processes, (ii) its small area (110 000 km^2), (iii) its complex topography (more than 70 % of the Honduras territory is considered mountain), and (iv) the scarce availability of historical weather data. Further work must test the use of a regional climate model as done in other similar areas (Guereña et al 2001; Mínguez et al 2007). From a crop physiology perspective, in Honduras farmers use extensive range varieties both in maize and common beans, these varieties showed a higher uncertainty in simulation studies (Díaz–Ambrona et al 2004).

5
Acknowledgments

CLIMATE CHANGE IMPACTS ON MAIZE AND DRY BEAN YIELDS... Carlos G. H. Díaz-Ambrona, Rubén Gigena y Carlos O. Mendoza
Revista Iberoamericana de Estudios de Desarrollo / Iberoamerican Journal of Development Studies
18_ Volumen/volume 2, número/issue 1 (2013), pp. 4-22. ISSN: 2254-2035

6
References

AUHING JI (1989). Evaluation of different doses and times from application of nitrogen, and methods of positioning of phosphorus on the yield of the maize in Zamorano (Honduras). Escuela Agrícola Panamericana Zamorano, Tegucigalpa, Honduras (in Spanish, with abstract in English)

BARRETO HJ, HARTKAMP AD (1999). Analysis of Maize Production in Honduras: Linking Census Data to Environment Variables through Geographic Information Systems. NRG–GIS Series 99–02. Mexico DF, Mexico

BARROW E, HULME M, SEMENOV MA (1996). Effect of using different methods in the construction of climate change scenarios: examples from Europe. Climate Research 7:195–211

BATRES J (1988). Evaluation of the effect of dose of nitrogen using urea and ammonium sulphate on the yield of the maize in Zamorano. Escuela Agrícola Panamericana Zamorano, Tegucigalpa, Honduras (in Spanish, with abstract in English)

BELLOCCHI G, MAESTRINI C, FILA G, FONTANA F (2002). Assessment of the effects of climate change a case study in northern Italy. In: proceeding s of the VII ESA Congress, Cordoba, Spain

CASTELLVI F, STÖCKLE CO (2001). Comparing the performance of WGEN and ClimGen in the generation of temperature and solar radiation. Transactions of the ASAE 446:1683–1687

CASTRO RE (2003). Detailed characterization of soil in Zamorano. Escuela Agrícola Panamericana Zamorano, Tegucigalpa, Honduras (in Spanish, with abstract in English)

DÍAZ–AMBRONA CH, GIGENA R, MENDOZA CO (2004). Global Climate Change and Food Security for Small Farmers in Honduras. In: New directions for a diverse planet. Proceedings of the 4th International Crop Science Congress, Brisbane, Australia 941–942

DONATELLI M, TUBIELLO FN, PERUCH U, ROSENZWEIG C (2002). Impacts of climate change and elevated CO2 on sugar beet production in Northern and Central Italy. Italian Journal of Agronomy 6:133–142

FERNÁNDEZ JV (2003). Detailed characterization of soil in Zamorano for pasture management. Honduras. Escuela Agrícola Panamericana Zamorano, Tegucigalpa, Honduras (in Spanish, with abstract in English)

FAO (1995). Digital Soil Map of the World and Derived Soil Properties; Version 3.5. Landand Water Digital Media Series 1; Food and Agriculture Organization of the United Nations [FAO], Rome, Italy

FAO (2011). FAOSTAT: FAO Statistical Databases. Food and Agriculture Organization of the United Nations [FAO], Rome, Italy. http://www.fao.org, accessed 27 September 2011

FUENTES PA (1991). Determination of economic and technical optimal levels of density and fertilization within Hybrid Maize B–833 under the climatic conditions of the valley of Yeguare. Escuela Agrícola Panamericana Zamorano, Tegucigalpa, Honduras (in Spanish, with abstract in English)

GUEREÑA A, RUIZ–RAMOS M, DÍAZ–AMBRONA CH, CONDE JR, MÍNGUEZ MI (2001). Assessment of climate change and agriculture in Spain using climate models. Agronomy Journal 93:237–249

GUERRERO JH (1988). Study the yield potential of common bean (*Phaseolus vulgaris* L.) in Honduras. Escuela Agrícola Panamericana Zamorano, Tegucigalpa, Honduras (in Spanish, with abstract in English)

HARO MA (1998). Lime and nitrogen fertilization effect on yield and profit of common bean. Escuela Agrícola Panamericana Zamorano, Tegucigalpa, Honduras (in Spanish, with abstract in English)

HINTZE LH, RENKOWB M, SAIN G (2003). Variety characteristics and maize adoption in Honduras. Agricultural Economics 29:307–317

CLIMATE CHANGE IMPACTS ON MAIZE AND DRY BEAN YIELDS… Carlos G. H. Díaz-Ambrona, Rubén Gigena y Carlos O. Mendoza
Revista Iberoamericana de Estudios de Desarrollo / Iberoamerican Journal of Development Studies
Volumen/volume 2, número/issue 1 (2013), pp. 4-22. ISSN: 2254-2035   **_19**

HULME M, WIGLEY TML, BARROW EM, RAPER SCB, CENTELLA A, SMITH S, CHIPANSHI A (2000). Using a climate scenario generator in vulnerability and adaptation assessments: MAGICC and SCENGEN Workbook. Climatic Research Unit, University of East Anglia, Norwich, UK

IGLESIAS A, ROSENZWEIG C, PEREIRA D (2000). Agricultural impacts of climate change in Spain: developing tools for a spatial analysis. Global Environmental Change–Human and Policy Dimensions 10:69–80

IPCC (2000). Emissions Scenarios. Prepared by N Nakicenovic and R Swart, Cambridge University Press, UK, 570. Available from Cambridge University Press, The Edinburgh Building Shaftesbury Road, Cambridge CB2 2RU, England http://www.ipcc.ch/ipccreports/sres/emission accessed 22 October 2012

IPCC–TGCIA (1999). Guidelines on the Use of Scenario Data for Climate Impact and Adaptation Assessment. Version 1. Prepared by Carter; TR; M. Hulme; and M. Lal; Intergovernmental Panel on Climate Change; Task Group on Scenarios for Climate Impact Assessment, Bern, Switzerland

JANSEN HGP, PENDER J, DAMON A, SCHIPPER R (2006). Rural Development Policies and Sustainable Land Use in the Hillside Areas of Honduras: A Quantitative Livelihoods Approach. Research report 147, International Food Policy Research Institute, Washington, USA http://www.ifpri.org/sites/default/files/publications/rr147.pdf accessed 22 October 2012

JONES PG, THORNTON PK (2000). MarkSim: Software to generate daily weather data for Latin America and Africa. Agronomy Journal 93:445–453

JONES PG, THORNTON PK (2003). The potential impacts of climate change on maize production in Africa and Latin America in 2055. Global Environmental Change 13:51–59

JOVANOVIC NZ, ANNANDALE JG, BENADE N, CAMPBELL GS 2003. CLIMGEN–UP: A user–friendly weather data generator. South African Journal of Plant and Soil 20:203–205

LOAGUE K, GREEN RE (1991). Statistical and graphical methods for evaluating solute transport models: overview and application. Journal of Contamination Hydrology 7:51–73

MEARNS LO, EASTERLING W, HAYS C (2001). Comparison of agricultural impacts of climate change calculated from high and low resolution climate model scenarios. Part I: The uncertainty due to spatial scale. Climate Change 51:131–172

MEARNS LO, GIORGI F, MCDANIEL L, SHIELDS C (2003). Climate scenarios for the southeast U.S. based on GCM and regional model simulations. Climate Change 60:7–35

MÍNGUEZ MI, RUIZ–RAMOS M, DÍAZ–AMBRONA CH, QUEMADA M, SAU F (2007). First–order impacts on winter and summer crops assessed with various high–resolution climate models in the Iberian Peninsula. Climate Change 81:343–355

MONTEITH JL (1977). Climate and crop efficiency of crop production in Britain. Philosophical Transactions of the Royal Society B 281:277–329

PARRY ML, ROSENZWEIG C, IGLESIAS A, FISCHER G, LIVERMORE M (1999). Climate change and world food security: A new assessment. Global Environmental Change 9:51–67

PARRY ML, ROSENZWEIG C, IGLESIAS A, FISCHER G, LIVERMORE M (2004). Effects of climate change on global food production under SRES emissions and socio–economic scenarios. Global Environmental Change 14:53–67

PAZ F, MATA JH (1999). Weather data from FHIA 1986–1998. Fundación Hondureña de Investigación Agrícola, La Lima, Honduras (in Spanish)

REILLY J (1996). Climate Change; global agriculture and regional vulberability, 237–266. In: Bazzaz F, Sombrock W. Eds. Global Climate Change and Agricultural Production. Wiley, Chichester, UK

ROBLETO EA (1988). Effect of the fertilization with calcium, phosphorus and molybdenum in the nitrogen fixation and yield common bean. Escuela Agrícola Panamericana Zamorano, Tegucigalpa, Honduras (in Spanish, with abstract in English)

RUBIO R (2002). The effect of nitrogen leaf fertilization on maize. Escuela Agrícola Panamericana Zamorano, Tegucigalpa, Honduras (in Spanish, with abstract in English)

CLIMATE CHANGE IMPACTS ON MAIZE AND DRY BEAN YIELDS… Carlos G. H. Díaz-Ambrona, Rubén Gigena y Carlos O. Mendoza
Revista Iberoamericana de Estudios de Desarrollo / Iberoamerican Journal of Development Studies
20_ Volumen/volume 2, número/issue 1 (2013), pp. 4-22. ISSN: 2254-2035

RUIZ–RAMOS M, MÍNGUEZ M (2010). Evaluating uncertainty in climate change impacts on crop productivity in the Iberian Peninsula. Climate Research 44: 69–82

SCOTT MJ, VAIL LW, JAKSCH JA, STÖCKLE CO, KEMANIAN AR (2004). Water exchanges: tools to beat El Niño climate variability in irrigated agriculture. Journal of the American Water Management Association 40(1):15–31

SEMENOV MA, BROOKS RJ, BARROW EM, RICHARDSON CW (1998). Comparison of the WGEN and LARS–WG stochastic weather generators for diverse climates. Climate research 10:95–107

SRES (2000). Special Report on Emissions Scenarios: A special report of Working Group III of the Intergovernmental Panel on Climate Change, Cambridge University

STÖCKLE CO, NELSON R (2001). Cropping Systems Simulation Model User's Manual. Biological Systems Engineering Department; Washington State University. http://www.bsyse.wsu.edu/CS_Suite, accessed 27 September 2011

STÖCKLE CO, CAMPBELL GS, NELSON R (1999). ClimGen manual. Biological Systems Engineering Department; Washington State University, Pullman, WA, USA

STÖCKLE CO, DONATELLI M, NELSON R (2003). CropSyst; a cropping systems simulation model. European Journal of Agronomy 18:289–307

STÖCKLE CO, NELSON R, DONATELLI M, CASTELLVI F (2001). ClimGen: a flexible weather generation program. In: Donatelli M (ed.). Proceedings of the 2nd International Symposium Modelling Cropping Systems, European Society of Agronomy, Florence, Italy 34–41

TANNER CB, SINCLAIR TR (1983). Efficient water use in crop production: research or re–search? In: Taylor H, Jordan WR, Sinclair TR (eds.). Limitations to efficient water use in crop production. American Society for Agronomy, Madison, WI, USA 1–27

TUBIELLO FN, DONATELLI M, ROSENZWEIG C, STÖCKLE CO (2000). Effects of climate change and elevated CO_2 on cropping systems: model predictions at two Italian locations. European Journal of Agronomy 13:179–189

VILLALOBOS F, ORGAZ F, TESTI L, FERERES E (1999). The use of synthetic weather data for strategy analysis in cropping system modelling. In: M. Donatelli (ed.). Proceedings of the International Symposium Modelling Cropping Systems. European Society for Agronomy, Lérida, Spain 269–270

VILLASECA I (2001). The effect of sowing density and nitrogen on maize yield in Zamorano (Honduras). Escuela Agrícola Panamericana Zamorano, Tegucigalpa, Honduras (in Spanish, with abstract in English)

WIGLEY TML (2003). MAGICC/SCENGEN 4.1: Technical Manual. UCAR–Climate and Global Dynamics Division, Boulder, Colorado. http://www.cgd.ucar.edu/cas/wigley/magicc/index.html, accessed 27 September 2011

WIGLEY TML, SMITH SJ, PRATHER MJ (2002). Radiative forcing due to reactive gas emissions. Journal of Climate 15:2690–2696

7
Annex: List of acromyms

A2:   SRES scenario family A2

B2:   SRES scenario family B2

ClimGen: Climate weather generator software

CropSyst: Cropping systems simulation dynamic model software

GCM: General circulation model

GFDL: Geophysical Fluids Dynamics Lab

GISS: Goddard Institute for Space Studies

HAD295:   A general circulation model for the Hadley Centre Coupled Model version 2

HAD300:   A general circulation model for the Hadley Centre Coupled Model version 3

IPCC: Intergovernmental Panel on Climate Change

MAGICC: Model for the Assessment of Greenhouse–gas Induced Climate Change

CLIMATE CHANGE IMPACTS ON MAIZE AND DRY BEAN YIELDS… Carlos G. H. Díaz-Ambrona, Rubén Gigena y Carlos O. Mendoza
Revista Iberoamericana de Estudios de Desarrollo / Iberoamerican Journal of Development Studies
Volumen/volume 2, número/issue 1 (2013), pp. 4-22. ISSN: 2254-2035   _21

METART: Meteorological data and derived products from FAO
masl: Meters above sea level
ppmv: Parts per million by volume (10^6)
RCM: Regional circulation model
RMSE: Root mena square error
SCENGEN: Scenario Generator model
SRES: Special Report on Emissions Scenarios
UKMO: United Kingdom Meteorological Office

CLIMATE CHANGE IMPACTS ON MAIZE AND DRY BEAN YIELDS... Carlos G. H. Díaz-Ambrona, Rubén Gigena y Carlos O. Mendoza
Revista Iberoamericana de Estudios de Desarrollo / Iberoamerican Journal of Development Studies
22_ Volumen/volume 2, número/issue 1 (2013), pp. 4-22. ISSN: 2254-2035