

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

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ResumenAbstract

1. Introduction
2. Material and Methods
 - 2.1. Field experiments
 - 2.2. Observed weather data
 - 2.3. Synthetic base climate
 - 2.4. Climate change scenarios
 - 2.5. Downscaling technique
 - 2.6. Cropping system simulation model
3. Results
 - 3.1. Crop model performance
 - 3.2. Baseline climate
 - 3.3. Climate change scenarios and crop production
4. Discussion and conclusion
5. Acknowledgments
6. References
7. Annex: List of acronyms

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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

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

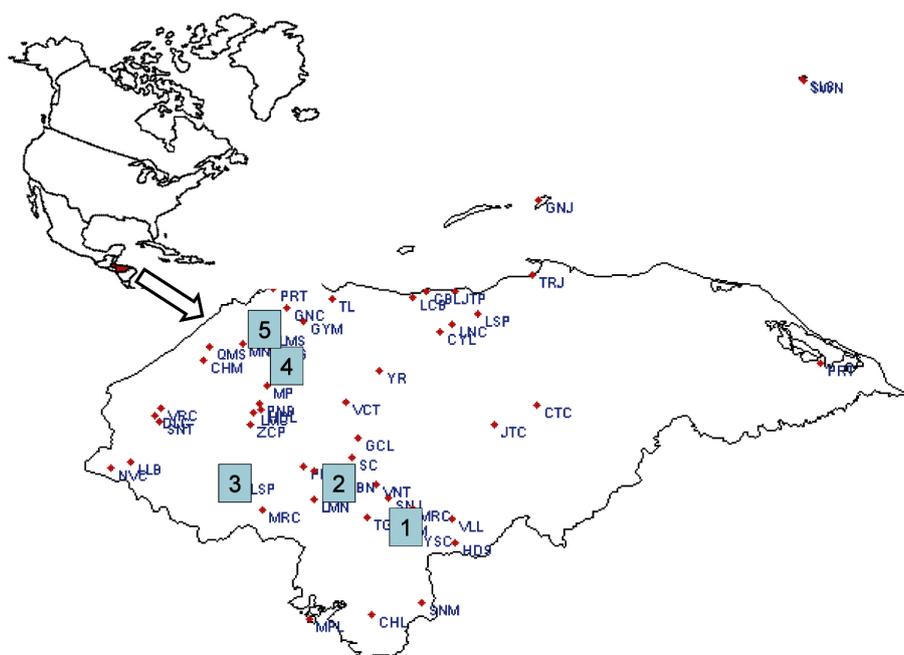


Figure 1
Location and weather station in Honduras: 1, Zamorano; 2, Comayagua; 3, La Esperanza; 4, La Lima 5, Valle de Sula. Red points are weather stations with monthly data available at METART from FAO.

	Valle de Sula	La Lima	Comayagua	Zamorano	La Esperanza
<i>Mean air temperature °C</i>					
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
<i>Precipitation mm</i>					
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 15° 44' 11", longitude W 87° 49' 15", 10 masl, from 1986 to 1998), La Lima (Latitude 15° 25' 36", longitude W 87° 56' 07", 30 masl, from 1987 to 1998), Comayagua (Latitude 14° 24' 18", longitude W 87° 39' 40", 579 masl, from 1995 to 1998), Zamorano (Latitude 14° 00' 45" N, longitude W 87° 00' 79", 780 masl, from 1945 to 2003) and La Esperanza (Latitude 14° 18' 45", longitude W 88° 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-TGCI 1999). The A2 family scenario is based on population projection of 15.1 billion by 2100 and to 635–856 ppm CO₂ and the B2 family scenario is based on population projection of 10.4 billion by 2100 and corresponds to 500–600 ppm CO₂ 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,

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 CO₂ 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.

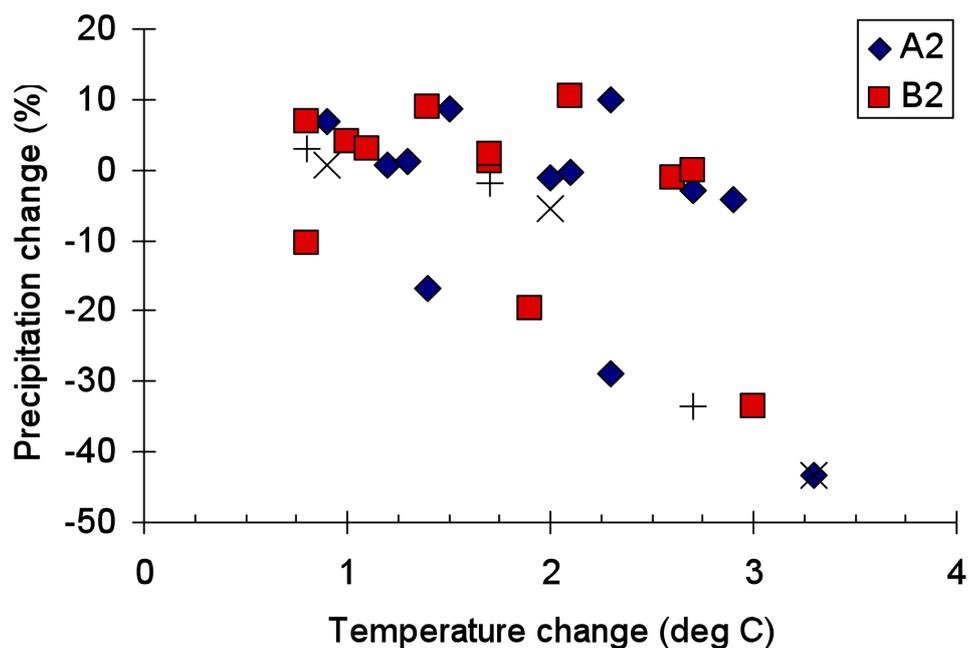


Figure 2
Changes in average annual temperature and precipitation percentage for the 2070–2099 relative to 1961–1990 from 24 combinations of different Global Climate Models and scenarios SRES A2 and B2 for Honduras grid from MAGICC SCENGEN software. The average chosen scenarios low, medium and high changes for A2 (x) 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.

Month	Scenario					
	A2			B2		
	High	Medium	Low	High	Medium	Low
<i>Projected increases in mean air temperature °C</i>						
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
<i>Projected changes in mean cumulative precipitation %</i>						
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 CO₂ 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 CO₂ on crop growth. The model uses the radiation and

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 CO₂ 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	°C	10	3
Cut-off temperature	°C	30	22
Optimum mean daily temperature for growth	°C	20	20
Emergence	°C day	117	100
Leaf duration degree–days	°C day	600	700
Begin flowering	°C day	898	1000
Peak leaf area index (LAI)	°C day	800	1040
Begin grain filling	°C day	1211	1020
Physiological maturity	°C day	1669	1500
Maximum rooting depth	m	0.80	1.50
Maximum water uptake	mm/day	14	10
Maximum expected LAI	m ² /m ²	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 /m ² 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.

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 masl	Soil depth m	pH	Hydrologic condition	Texture			Soil total nitrogen m	Soil organic matter %
					Sand %	Clay %	Silt %		
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

(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).

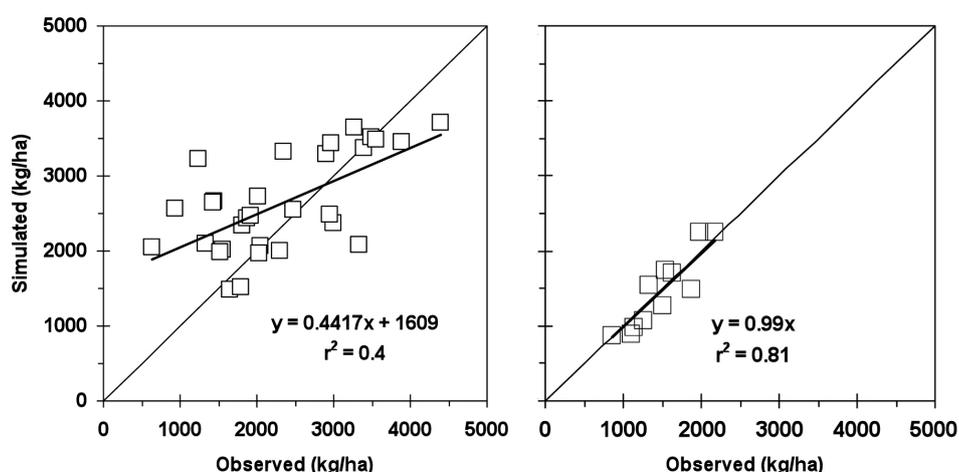


Figure 3
Observed versus simulated yield with cropping systems dynamic model CropSyst in Honduras for maize and common bean.

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 variability, 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.

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

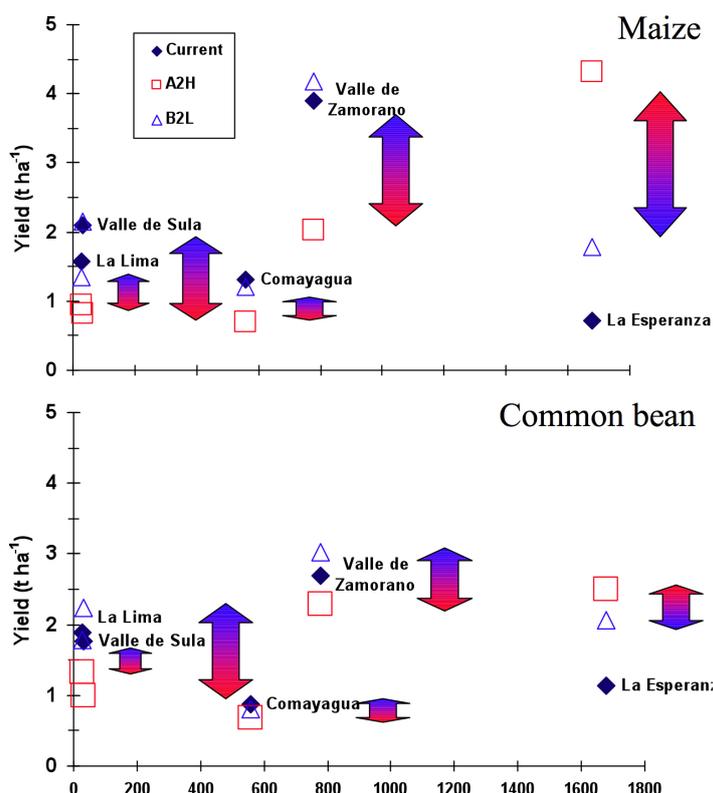


Figure 4

Simulated maize and common bean average yields for different location and scenarios for current and extremes SRES marker scenarios A2 and B2 projected a CO₂ concentration of 718 ppmv and 566 ppmv at 2070-2099 period, respectively arrow shows yield range between scenarios.

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 °C 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 °C (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,

the average of simulated 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 °C 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 °C optimal growth temperature and 20 °C 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.

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 km²), (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).

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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

METART: Meteorological data and derived products from FAO
masl: Meters above sea level
ppmv: Parts per million by volume (10⁶)
RCM: Regional circulation model
RMSE: Root mena square error
SCENGEN: Scenario Generator model
SRES: Special Report on Emissions Scenarios
UKMO: United Kingdom Meteorological Office