

**ASSESSING POTENTIAL IMPACTS OF CO<sub>2</sub>-  
AND DEFORESTATION - INDUCED CLIMATE CHANGE  
ON MAIZE AND BLACK BEAN IN VENEZUELA**

**EVALUACIÓN DE LOS IMPACTOS POTENCIALES DE CAMBIOS  
CLIMÁTICOS INDUCIDOS POR EFECTO INVERNADERO  
Y POR LA DEFORESTACIÓN SOBRE EL CULTIVO  
DE MAÍZ Y CARAOTA EN VENEZUELA**

*Miguel F. Acevedo<sup>1,2</sup>, Ramón Jaimez<sup>2,3</sup>, Carlos E. Maytín<sup>4</sup>, Giorgio Tonella<sup>2</sup> and Mark A. Harwell<sup>5</sup>*

<sup>1</sup> *Institute of Applied Sciences and Department of Geography, University of North Texas,  
Denton TX 76203, USA.*

<sup>2</sup> *Centro de Investigación y Proyectos en Simulación y Modelos (CESIMO), Facultad de  
Ingeniería, Universidad de Los Andes, Mérida 5101, Venezuela.*

<sup>3</sup> *Instituto de Investigaciones Agropecuarias, Facultad de Ciencias Forestales, Universidad de  
Los Andes, Mérida 5101, Venezuela.*

<sup>4</sup> *Centro de Investigaciones Ecológicas de los Andes Tropicales (CIELAT), Facultad de Ciencias,  
Universidad de Los Andes, Mérida 5101, Venezuela. Now at: HIDROANDES, Barinas, Venezuela*

<sup>5</sup> *Rosenstiel School of Marine and Atmospheric Science, University of Miami, Miami FL, 33149, USA.*

**ABSTRACT**

We summarize the potential impacts of climate change on the yield of maize (*Zea mays*) and black bean (*Phaseolus vulgaris* L.) at important agricultural sites in Venezuela. The effects of greenhouse-induced global-scale climatic changes and deforestation-induced continental-scale climatic changes were analyzed for both staple crops. The enhanced greenhouse climate scenarios (GH) were derived from atmospheric General Circulation Models for doubled CO<sub>2</sub> conditions. GH scenarios of three levels of sensitivity were defined (low, medium and high) from the lower and upper bounds of GCM-derived temperature projections. These GH scenarios assume increased air temperature for both the wet and dry season and increased rainfall and decreased incoming solar radiation for the wet season. Direct effects of increased atmospheric CO<sub>2</sub> were included in the bean simulations but not in the maize simulations. The deforestation scenarios (DEF) assume increased air temperature, increased incoming solar radiation and decreased rainfall, as predicted by coupled atmosphere-biosphere models for extensive deforestation of the Amazon basin. The CERES-Maize and BEANGRO crop simulation models, from the Decision Support System for Agrotechnology Transfer (DSSAT), were used for assessing impacts on yield of corn and black bean respectively. The results are only relative because the simulations assumed non-limiting nutrients and no damage from pests or from excess water. The assessments consisted of simulated cultivations of the CENIAP PB-8 maize cultivar grown during the wet season at three sites for two baseline years (in order to cover different rainfall conditions), and the TACARIGUA black bean cultivar grown during the dry season at three sites, for only one baseline climate year. All GH scenarios caused a decrease in yield of corn at all sites: the phenological phases were shortened and the number and weight of kernels were reduced. Low sensitivity GH scenarios produced a slight increase in bean yield, but medium and high GH scenarios decreased bean yield, in spite of the partial compensation by atmospheric CO<sub>2</sub> enrichment. Increases of precipitation in GH scenarios had no effects on maize yield, because the sites already have adequate precipitation; however, the crop models used here do not account for potential negative effects of excess water. DEF scenarios produced relatively smaller changes in maize and bean yield. Increased solar radiation increased maize yields for the relatively small increase of air temperatures used in the DEF scenarios. Decrease of bean harvest index for all scenarios indicates that yield is more sensitive to air temperature change than is biomass. The potential reductions in maize and bean yield will most likely be due to increasing temperatures and not to rainfall changes.

**KEY WORDS:** climate change, greenhouse effect, deforestation, maize, beans, yield, Venezuela.

## RESUMEN

En este trabajo se simulan los impactos potenciales de cambios climáticos sobre el rendimiento del maíz (*Zea mays*) y las caraotas (*Phaseolus vulgaris* L.) en varias localidades agrícolas de Venezuela. Se analizan tanto los efectos de cambios climáticos globales inducidos por un incremento del efecto invernadero como los efectos de los cambios climáticos regionales inducidos por deforestación extensiva. Los escenarios de cambio climático debido al aumento del efecto invernadero (GH) se obtuvieron de modelos de circulación general de la atmósfera asumiendo una duplicación de la concentración de CO<sub>2</sub> atmosférico. Estos escenarios (GH) se diseñaron con tres niveles de sensibilidad (baja, media y alta) a partir de las cotas superior e inferior de los pronósticos de temperatura derivados de los modelos de circulación general atmosférica. Estos escenarios GH suponen un incremento de la temperatura del aire para ambas estaciones (seca y de lluvias) y un incremento de precipitación acompañado de un decremento de radiación solar incidente para la estación de lluvias. Los efectos directos del incremento de CO<sub>2</sub> se incluyeron en las simulaciones de caraota pero no en las de maíz. Los escenarios de deforestación (DEF) suponen incrementos de la temperatura del aire y de la radiación solar incidente y un decremento de la precipitación, tal como lo predicen los modelos globales acoplados de atmósfera-biosfera cuando se someten a condiciones de deforestación extensiva de la cuenca Amazonica. Para evaluar los impactos sobre el rendimiento de maíz y caraotas se usaron los modelos de simulación CERES-Maize y BEANGRO, respectivamente, del Sistema de Apoyo Decisional para la Transferencia Agrotecnológica (DSSAT). Los resultados son solamente relativos ya que las simulaciones suponen que la productividad no está limitada por escasez de nutrientes, ni por plagas, ni por exceso de agua. Las evaluaciones consistieron en cultivos simulados del cultivar CENIAP PB-8 de maíz durante la estación de lluvias en tres localidades para dos años bases (con el fin de explorar condiciones diferentes de precipitación) y del cultivar TACARIGUA de caraota durante la estación seca en tres localidades para solamente un año base (ya que la siembra es de verano y no es necesario explorar condiciones diferentes de precipitación). Todos los escenarios GH causaron una reducción del rendimiento de maíz en todas las localidades: acortándose las duraciones de las fases fenológicas y reduciéndose el número y peso de los granos. El escenario GH de baja sensibilidad produjo un ligero incremento del rendimiento en la caraota, pero los escenarios GH de media y alta sensibilidad produjeron un decremento del rendimiento de caraota, a pesar de la compensación parcial por enriquecimiento del CO<sub>2</sub> atmosférico. Los aumentos de precipitación en los escenarios GH no tuvieron efecto sobre el rendimiento de maíz porque ninguna de las localidades presenta déficit hídrico; sin embargo, se debe anotar que los modelos de cultivos usados en este trabajo no incluyen efectos negativos potenciales debidos al exceso de agua. Los escenarios DEF produjeron cambios relativamente menores en los rendimientos de ambos cultivos. El aumento de radiación solar incremento los rendimientos de maíz en el caso de los cambios relativamente menores de temperatura usados en los escenarios DEF. Se obtuvo una disminución del índice de cosecha de caraota para todos los escenarios indicando que el rendimiento es más sensible al cambio de temperatura de lo que lo es la biomasa a dicho cambio. Las reducciones potenciales en los rendimientos de maíz y caraota observados en estas simulaciones se deben principalmente a los incrementos de temperatura y no a los cambios en precipitación.

**PALABRAS CLAVE:** cambio climático, efecto invernadero, deforestación, maíz, caraotas, rendimiento, Venezuela.

## INTRODUCTION

The research reported here is part of the Venezuela Case Study of the PAN-EARTH international project, which attempts to understand the vulnerabilities of regional agricultural and ecological systems to global climatic change (Harwell 1993). As a first step of this case study, interdisciplinary workshops evaluated the use of crop models to assess the impacts of global climate change on crop yield and developed scenarios of climate change associated with nuclear winter, the enhanced greenhouse effect and Amazonian deforestation (Robock *et al.* 1993). The potential impact of the greenhouse and deforestation scenarios was subsequently simulated for high yielding corn varieties grown in Venezuela, using the CERES-Maize model

(Maytín *et al.* 1995), and for black beans, using the BEANGRO model (Jaimez *et al.* 1993).

In this paper we summarize the physical and agricultural characteristics of Venezuela, the enhanced greenhouse and deforestation climate change scenarios, the CERES-Maize and BEANGRO models and the potential effects on the yield of both maize and black beans.

**The physical environment of Venezuela**

Venezuela is located in northernmost tropical South America, from 0 39'N to 12 12'N and 59 47'W to 73 23'W, (Figure 1), and occupies an area of nearly one million km<sup>2</sup>. Spatial heterogeneity of environmental conditions is pronounced for this relatively small area, and is determined by the

Caribbean sea, the Amazon basin and the Andes mountains. These conditions make Venezuela an interesting case study for assessing the potential impacts of global climate change in biologically diverse inter-tropical regions.

The mean annual temperature has a small seasonal variation but a wide range of spatial variation, and is as low as 0° C in some areas of the Andes and up to 28° C in the Maracaibo Lake area. Precipitation is influenced mainly by northeasterly winds and shifting of the Inter-Tropical Convergence Zone (ITCZ). Spatial patterns follow a N-S gradient in three rainfall belts: the *Coastal* in the north, with annual rainfall lower than 800 mm, the Orinoco *Llanos* (plains), with annual rainfall between 1000 and 2500 mm, and the southern *Guayana and Amazon* equatorial belt, with annual rainfall between 1500-3500 mm (Andressen 1989). Figure 1 illustrates this spatial gradient for the month of April which corresponds to the onset of the rainy season.

Seasonality of atmospheric circulation in the northern hemisphere determines temporal rainfall patterns. During the northern hemisphere summer, the easterlies extend from the surface to the high troposphere, causing rainfall events in northern Venezuela. In the plains, the rainy season lasts from April-May to October-November, with a peak in July-August (Andressen 1989).

Spatial heterogeneity is also exhibited by relief, geomorphology and soils. The higher parts of the Venezuelan *Andes* cross a quarter of the territory in the SW-NE direction segmenting the Maracaibo Lake Basin from the *Llanos* of the Orinoco river (Figure 1). The lower parts of the Venezuelan *Andes* and the *Coastal* range produce a series of valleys in the northern part of the country. A high proportion of the agriculturally valuable soils are located in those valleys, in the plains south of the Maracaibo Lake and in the western *Llanos* (Avilan and Eden 1986).

### **Agricultural systems in Venezuela**

Diversity of cultivars, soils, climate and technology is a characteristic of Venezuelan agricultural systems (Comerma 1989). Cereals

(maize, rice and sorghum) and oil crops (sesame, cotton and peanuts) are mainly grown in the plains; most vegetables, beans, roots and tuber crops are grown in the Andes and in the valleys of the northern region; some plantation crops (coffee, sugar cane, pineapple, oranges) are grown in the valleys of the northern region, and others (plantain and bananas) are grown south of Maracaibo Lake.

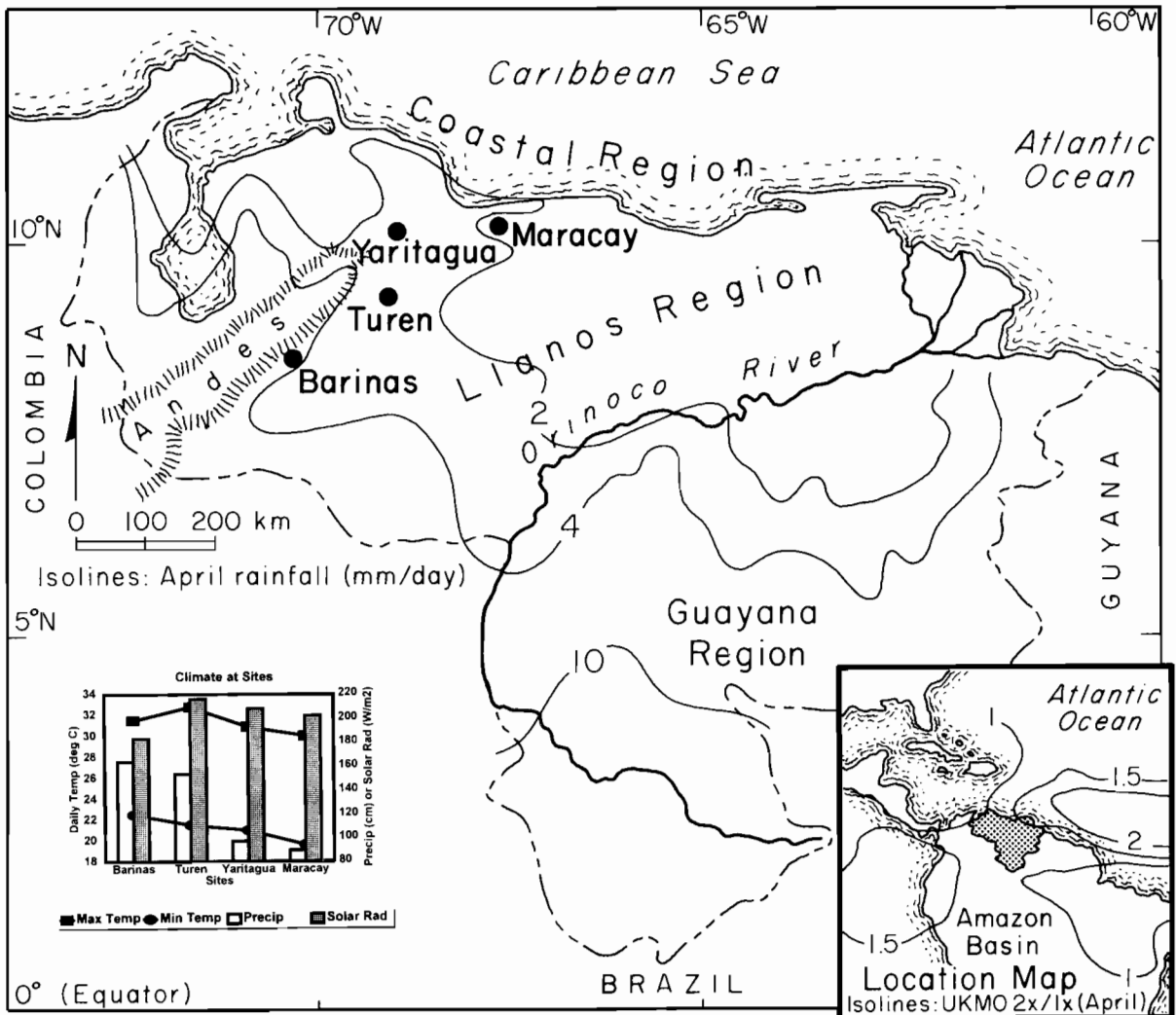
Cereals provide the most important caloric and protein input in the Venezuelan diet, and since 1986 occupy the largest area under cultivation, generating the largest production value. Maize is the cereal with the largest production and area under cultivation in Venezuela. Maize-producing areas of Venezuela are concentrated in the coastal valleys, the central plains, and the piedmont alluvial western plains. Legumes, after the cereals, provide the main protein input in the Venezuelan diet; several types of beans are important, including black beans which are grown mainly in the northern valleys. In 1992 maize and black bean production reached 852,352 and 27,437 metric tons, respectively (MAC 1993).

## **MATERIALS AND METHODS**

### **Study sites**

We selected four sites representative of the two crops and located in important agricultural regions, the western plains and the coastal valleys. For maize and bean simulations, we selected two sites in the western plains, Turén (9 15'N, 69 06'W, and 275 m in elevation) and Barinas (8 36' N, 70 12'W, and 189 m in elevation). We also selected two sites in the coastal valleys, Yaritagua (10 05'N, 69 07'W, and 375 m in elevation) for maize simulations, and Maracay (10 15'N, 67 39'W, and 436 m in elevation) for black bean simulations (Figure 1).

Yaritagua and Maracay are cool and sub-humid sites, with a dry season that lasts five months (November-March). In contrast, Barinas and Turén are warm and wet, with a dry season of only four months duration (December-March). Coastal influences are more pronounced in Yaritagua and Maracay.



**Figure 1.** Geographical location of study sites, main climate regions and April rainfall isolines. Lower left hand side corner: summary of the daily weather of selected study sites. Lower right hand side corner: relative location of Venezuela and the ratio of 2xCO<sub>2</sub>/1xCO<sub>2</sub> rainfall change as predicted by UKMO.

Soils in Turén are fertile but are often compacted (Comerma 1989). Soils in Barinas are not as fertile but have good physical conditions (Hetier *et al.* 1989). Those in Yaritagua and Maracay are of medium fertility and moderate moisture deficiency (Comerma 1989).

**Climate change scenario development**

Atmospheric general circulation models (GCM) have coarse horizontal resolution, especially relative

to that required for regional and local predictions in a small and heterogeneous area, such as Venezuela. For example, only four grid cells of the Goddard Institute of Space Studies (GISS) GCM (Hansen *et al.* 1984) cover all of Venezuela; two of these cells include both land and sea and simplify relief by flattening high mountains in the Andes. It is therefore necessary to scale down the GCM predictions (Robock *et al.* 1993).

Control runs of four low horizontal resolution GCMs (UKMO,  $5 \times 7.5$ , Wilson and Mitchell 1987; OSU,  $4 \times 5$ , Schlesinger and Zhao 1989; GISS,  $7.83 \times 10$ , Hansen *et al.* 1984; GFDL,  $4.4 \times 7.5$ , Wetherald and Manabe 1986) were compared with the observed monthly temperature and precipitation in January, April, July, and October for nine  $1 \times 1$  cells in Venezuela. There is broad correspondence between the GCM outputs and spatial patterns of local climatology, such as the N-S rainfall gradient, but the magnitudes of the rainfall are not very well predicted. The UKMO model was selected for the greenhouse  $2 \times \text{CO}_2$  climate change scenarios, because the results of the control simulation are closer to the magnitude and pattern of actual precipitation than the other models and therefore the  $2 \times \text{CO}_2$  simulation was considered more credible (Robock *et al.* 1993). For example, the ratio of  $2 \times \text{CO}_2 / 1 \times \text{CO}_2$  rainfall predicted by UKMO for the month of April is given in the lower right hand corner of Figure 1.

### Scenarios used

A total of eight greenhouse scenarios, four for the dry season (GH1d, GH2d, GH3d, GH4d) and four for the wet season (GH1w, GH2w, GH3w, GH4w) were defined (Table 1). Since UKMO is the most sensitive of the GCMs to  $\text{CO}_2$  changes, its perturbed results were used to establish an upper bound or high sensitivity scenario (GH4d and GH4w). This case was then scaled down to generate two other sensitivity categories: low (GH1d, GH1w) and medium. This medium sensitivity case was broken into one with rainfall increase (GH3d, GH3w) and one without (GH2d, GH2w), in order to account for uncertainty of rainfall prediction by the GCMs (see e.g., Sulzman *et al.* 1995).

It is assumed that solar radiation decreases, due to increased cloudiness, that the increase in daily minimum temperature is larger than the increase in the daily maximum temperature and that the number of rainfall events increases, but not their intensity, because in tropical areas only a few rain events account for most of the monthly precipitation (Riehl 1979). Scenarios based on increases of the frequency and intensity of severe tropical storms and hurricanes

were not used because the CERES-Maize and the BEANGRO models do not simulate the effects of excess rainfall, i.e., flooding and saturation problems.

For deforestation of the Amazon basin, the Shukla *et al.* (1990) coupled atmosphere-biosphere model was used to derive two altered climate scenarios, one for the dry season (DEFd) and one for the wet season (DEFw) (Table 1). The wet season scenario included changes in temperature, rainfall and radiation, whereas the dry season scenario only included changes in temperature.

Precipitation increases in the greenhouse wet season scenarios were constructed by adding rainfall days to the baseline climate series, adjoining these new rainy days to those occurring in the record, because isolated rainy days are less frequent than sequences of rainy days. For those days with increased rainfall, daily solar radiation was decreased proportional to the change in precipitation; for the remaining days, radiation was decreased proportional to half the increase in monthly precipitation (Robock *et al.* 1993, Maytín *et al.* 1995).

### Crop models

The CERES-Maize model version 2.10 (Ritchie *et al.* 1989a, Jones and Kiniry 1986) and the BEANGRO model version 1.1 (Hoogenboom *et al.* 1991) as included in the *Decision Support System for Agrotechnology Transfer (DSSAT)* (IBSNAT 1990) were used to simulate the effects of climatic change on maize and black beans. These models simulate phenology and yield of different varieties based on inputs of weather data, soil information and management practices. They are process-based models including, for example, development of vegetative and reproductive units, growth of leaves and stems, biomass production and partitioning. However, these models do not simulate the effects of weeds, diseases, insects, excessive rainfall and catastrophic events (other than drought).

The CERES-Maize and BEANGRO models have been extensively used for assessments of potential impacts of global climate change e.g. in the USA (Ritchie *et al.* 1989b, Rosenzweig 1989, 1990,

**Table 1.** Scenarios of climate change used for the crop simulations.

Scenario	Season	Max. daily temp. (°C)	Min. daily temp. (°C)	Monthly precip. (%)	Radiation with rain change (%)	Radiation without rain change (%)
DEFw	wet	+1	+1	-25	+10	+10
DEFd	dry	+1	+1	0	0	0
GH1w	wet	+1	+2	0	0	0
GH1d	dry	+1	+2	0	0	0
GH2w	wet	+2	+3	0	0	0
GH2d	dry	+2	+3	0	0	0
GH3w	wet	+2	+3	+20	-20	-10
GH3d	dry	+3	+4	0	0	0
GH4w	wet	+3	+4	+40	-40	-20
GH4d	dry	+4	+5	0	0	0

Peart *et al.* 1989, Adams *et al.* 1990). CERES-Maize has been used in Venezuela (Comerma 1986, 1989) and in other South American countries (Liu *et al.* 1989, Bowen *et al.* 1993). These models facilitate continuing assessment of climate change impacts within DSSAT (Hoogenboom *et al.* In press).

Data required by the CERES-Maize model v 2.10 and the BEANGRO model as implemented in DSSAT (IBSNAT 1988) include: management practices (sowing date and depth, planting density, irrigation and fertilization), daily climatic records (solar radiation, precipitation, maximum and minimum air temperatures), soil horizon characteristics (depth, texture, moist bulk density, organic material content, pH, field capacity and wilting point, albedo, type of drainage, permeability and root growth limitations), and genetic characteristics (crop specific coefficients).

The CERES-Maize's genetic coefficients are: duration of the juvenile phase, sensitivity to photoperiod, duration of kernel filling period, maximum number of kernels per plant and maximum rate of kernel filling. BEANGRO's genetic coefficients are: night length for minimum floral induction time, days from the end of the juvenile period to floral initiation, days for the induction phase, days for the period from first flower appearance to start of pod growth, days for the period from first flower appearance to end of

expansion of last leaf, days of the total reproductive period, number of trifoliates produced per day, area of normal leaf, number of pods produced per day, rate of dry matter accumulation of individual pods, mean number of seeds per pod and seed filling rate.

Crop management was simulated based on current cultivation practices in order to explore potential consequences of climate change on the two crops as they are currently grown in Venezuela. For example, maize was planted in the wet season, planting day varying from May to June, at a density of 5 plants m<sup>-2</sup> under rainfed conditions (Maytin *et al.* 1995), whereas for beans, simulations corresponded to the dry season, planting in January, at a density of 19 plants m<sup>-2</sup> and water added at the rate of 25-30 mm every 7 days to complete a total of 315 mm during the cultivation cycle (Jaimez *et al.* 1993).

Soil water content at planting day was set at field capacity. Simulations with lower values reflecting restricted water availability for maize are reported in Maytin *et al.* (1995). Nitrogen was assumed not to be limited and therefore not simulated; nitrogen deficiency could be enhanced by increased rainfall and will be addressed in a subsequent paper.

Calibrations of CERES-Maize used CENIAP PB8, a hybrid maize cultivar grown in Venezuela (Maytin *et al.* 1995); calibrations of BEANGRO

used the TACARIGUA black bean cultivar (Jaimez *et al.* 1993). Values for the genetic coefficients used for the TACARIGUA cultivar are the same as PORRILLO SINTETICO, which has been tested for BEANGRO (Jaimez *et al.* 1993).

### Baseline years and sensitivity analysis

For maize, baseline conditions (i.e., the daily climatic data to be perturbed according to each scenario) consisted of two years of observed weather for each site, one year with average precipitation and another year with lower than average rainfall (Maytín *et al.* 1995). For beans, the average of weather data for five years from each location was used as the baseline condition (Jaimez *et al.* 1993). Climatic records from stations operated by the *Fondo Nacional de Investigaciones Agropecuarias* (FONAIAP) and by the *Ministry for the Environment and Renewable Natural Resources* (MARNR) were used.

Sensitivity to systematic changes in air temperature, precipitation and solar radiation was analyzed for CERES-Maize (Maytín *et al.* 1995), whereas sensitivity to air temperature and atmospheric CO<sub>2</sub> was analyzed for BEANGRO (Jaimez *et al.* 1993). The CO<sub>2</sub> concentration was varied from the baseline value of 330 ppm to 528 ppm (+60%), which represents the CO<sub>2</sub> concentration in the pool of greenhouse gases for equivalent 2xCO<sub>2</sub> conditions. Rainfall and solar radiation were not explored for BEANGRO because the GH scenarios do not include changes in these parameters during the dry season. The direct effect of increased CO<sub>2</sub> concentration on the ecophysiology of maize was not studied, because studies combining direct and indirect effects (e.g., Peart *et al.* 1989; Rosenzweig 1989, 1990) as well as experimental data (Rose 1989) indicate that this direct effect is not as significant in plants with the C4 photosynthetic mechanisms.

This sensitivity analysis showed that the effects of increasing air temperature on maize phenology and yield were significant at all sites, suggesting that temperature is already too high

for optimal growth of maize at these sites; the shortest life cycle occurred in Barinas (the warmest site), while the longest life cycle occurred in Yaritagua (the cooler site). The effects of changing precipitation on maize yield were small at Turén and Barinas, suggesting that there is no water stress at either of these two sites. Phenology was not sensitive to rainfall changes because the phase calculations in CERES-Maize are a function of only air temperature. Changes in solar radiation caused a direct response in maize yield, consistent with high light-saturation levels of a C4 plant, except at Turén, suggesting that solar radiation is not a limiting factor at this site.

Small changes in the duration of phenological stages of beans were obtained at all sites for the temperature range explored. Phenology was not sensitive to CO<sub>2</sub>. The BEANGRO sensitivity runs revealed yield reductions for large temperature increases, but increases in yield were obtained for small temperature increases as well as for increasing CO<sub>2</sub> concentration. Reduced bean yields can be attributed to increased water stress due to high temperatures and resulting high evapotranspiration rates. Indeed, the yield reductions are cut in half by unrestricted irrigation rate at all times during cultivation. The decrease in photosynthetic rates and the increase in respiration at high temperatures reduce the amount of carbohydrates available for allocation to growth and reproduction (dependent on temperature in BEANGRO). As temperature increases, the predicted number of pods and their weight decreases, the stem/biomass ratio increases and the allocation to leaves remains almost constant (Jaimez *et al.* 1993).

## RESULTS

At all sites and for all scenarios temperature increases shortened the phenological phases of maize, including the time from emergence to physiological maturity and the duration of the kernel-filling phase. The phase shortening was less

pronounced for the deforestation scenario and more so for the greenhouse scenarios (Figure 2) because temperature is the only factor determining phase duration in CERES-Maize. This formulation also explains why the changes in the duration of the phenological stages obtained for GH2w and GH3w were the same in spite of the different values of precipitation and radiation used in these scenarios.

Greenhouse scenarios caused a decrease in maize yield at all sites, but the impact was slightly larger in Barinas. The deforestation scenario increased yield slightly for the average baseline year in Barinas, but not in Turén or Yaritagua. The reductions of yield were greater for perturbed runs corresponding to average baseline years (i.e., average rainfall) than those corresponding to dry baseline years (i.e., lower than average rainfall), except in Turén (Figure 3). Increased rainfall in scenarios GH3w and GH4w does not have an effect on maize yield because there is sufficient rainfall under baseline conditions, and because the simulations assume planting with soil water at field capacity.

All GH scenarios produce a decrease of number and weight of the maize kernels; scenarios with decreased solar radiation (GH3w and GH4w) resulted in larger reduction of number of kernels than reduction of kernel weight (Figure 4). This result suggests that current solar radiation in these sites may not be adequate for achieving optimal number of kernels. The deforestation scenario resulted in slight increase of number of kernels for the average baseline year and a slight decrease for the dry baseline year (Figure 4a).

BEANGRO simulations show black bean yield reductions with increasing temperature for all scenarios, except for the low sensitivity GH1d scenario (Figure 5). Yield decreases significantly for the medium and high sensitivity scenarios, especially for the GH3d and GH4d scenarios. These results indicate that simulated CO<sub>2</sub> enrichment can compensate only partially for yield reduction at higher temperatures. The DEFd scenario also reduces yield due to increased temperatures due to the absence of CO<sub>2</sub> enrichment compensation under

this scenario. Decrease in yield in Turén was slightly larger than in Barinas and Maracay (Figure 5a).

Increasing temperature always reduces the harvest index (ratio of yield to total biomass) of black bean, even for low temperature increases. Changes in the number of days elapsed to maturity are small; the low sensitivity GH scenario produced small increments in the number of days to flowering, except at Turén (which is the warmest site). As mentioned in the previous section, increasing temperature reduces the number of pods and thereby affects the yield (Jaimez *et al.* 1993).

## DISCUSSION AND CONCLUSIONS

The duration of the phenological stages of maize were affected by temperature and not by precipitation and radiation, because temperature is the only factor determining those durations in CERES-Maize. Previous modeling work has shown increasing temperatures to have a negative effect on modeled maize yield because of the decrease in the duration of the life cycle (Curry *et al.* 1990, Peart *et al.* 1989).

Reductions of the total number of kernels for scenarios with decreased solar radiation indicates that current solar radiation in these sites may not be adequate for achieving optimal number of kernels. This possibility is further supported by the slight yield increase under the deforestation scenario, for which the increased number of kernels due to increased solar radiation compensates for the shortening of the grain-filling time induced by thermal stress.

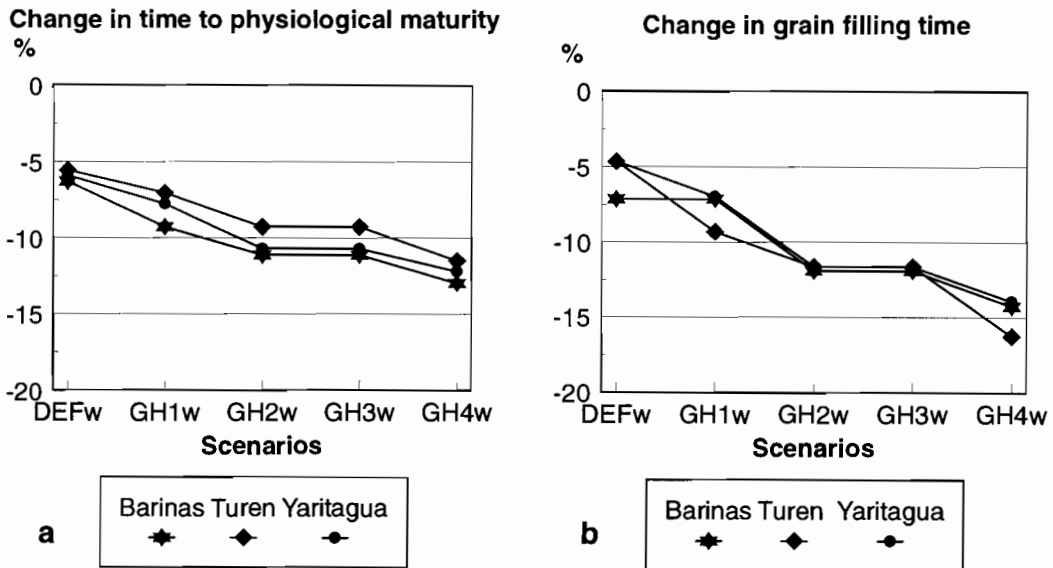
The assumption of planting with soil water at field capacity could mask some of the potential effects of changes in rainfall and should be modified in future work in order to cover a wider range of potential effects of rainfall change, especially if scenarios with decreased rainfall are considered to be plausible.

The CERES-maize model does not simulate excess water problems in maize cultivation. At the drier site, Yaritagua, the deforestation and the greenhouse scenarios with temperature changes only



## Effects on Maize Phenology

### Average Baseline Year



**Figure 2.** Impact of climate change, caused by the enhanced greenhouse effect and deforestation, on the phenology of maize at Barinas, Turén and Yaritagua. Changes, in % with respect to average baseline year, of the time to reach physiological maturity (a) and of the grain filling time (b).

(GH1w and GH2w) could cause decrease of maize yield due to water deficit.

Only the indirect effects of increasing  $\text{CO}_2$ , i.e. global climatic change, were estimated in the maize simulations. The direct effects of increasing atmospheric  $\text{CO}_2$  on plant ecophysiology, i.e. increased photosynthetic rate and water-use efficiency, were not simulated for maize because these direct effects may be small in plants with C4 pathways and may be constrained by other environmental or biological limiting factors, but this remains a controversial issue (e.g. Idso and Idso 1994 vs Bazzaz 1990, Fajer and Bazzaz 1992, Diaz *et al.* 1993).

The increase in bean yield for the low sensitivity GH scenario is achieved by simulated  $\text{CO}_2$  enrichment overcompensating for yield reduction at these small temperature increments. Significant bean yield decreases for medium and high sensitivity GH scenarios indicate that, even when assumed to increase photosynthetic rates,  $\text{CO}_2$  enrichment can compensate only partially for yield reduction at higher temperatures.

Also, reductions of modeled black bean harvest index with increasing temperatures suggest that bean yield is more sensitive than biomass to increases in temperature. A reduction of the number of pods by increasing temperatures seems to be the main factor affecting bean yield.

Bean yield reductions are smaller than those of maize for the low sensitivity GH scenario, due to simulated  $\text{CO}_2$  enrichment compensation in beans for small temperature increases. But bean yield reductions are more pronounced than maize yield reductions for medium and high sensitivity scenarios. The pronounced reductions of bean yield are also due to increased water demand, at higher temperatures, which is not met by the simulated irrigation schedule.

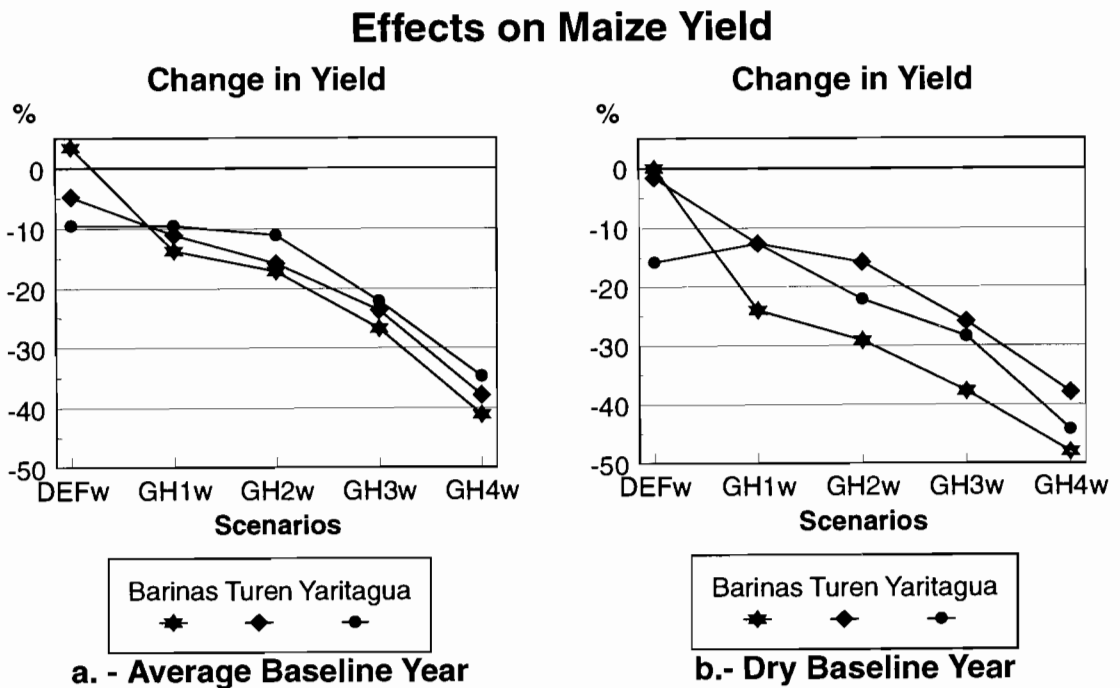
The results presented here should not be interpreted as «predictions» of maize and black bean yield under future climatic conditions, but rather as an assessment of the potential vulnerability of these crops, as cultivated in Venezuela, to a reasonable range of future climate scenarios for the region.

The results of this study suggest that maize and bean yields in Venezuela could potentially be reduced by climate changes induced by an enhanced greenhouse effect and Amazon deforestation. The response of the crop models used here, suggest that the potential reductions in yield will most likely be due to increasing temperatures and not to rainfall changes.

As used here, the crop models did not include nutrient limitations, erosion, chemical changes in the soils, pests and weeds; therefore, it is possible that the estimated reductions in yield are underestimated. The effect of temperature and solar radiation changes as well as precipitation decreases can be examined with the crop models used, but the total effect of precipitation increases cannot be inferred because of the current inability of these crop models to treat excess rainfall. Incorporating effects of excess rainfall is needed in order to improve future analyses. Another model which could be used in these assessments is the *Erosion Productivity Impact Calculator* (EPIC, Williams *et al.* 1990). This model has been recently

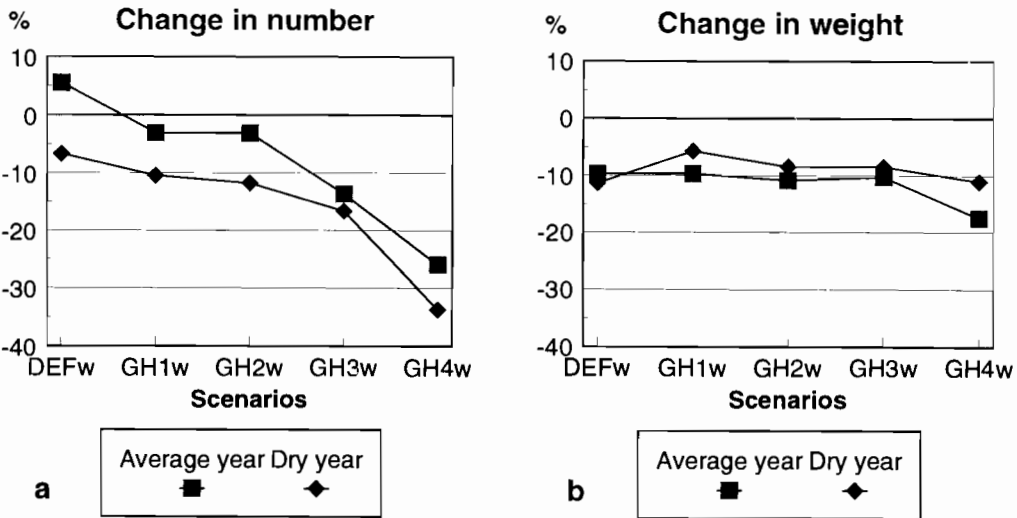
used for the assessment of climate change effects on crop yields in the Missouri-Iowa-Nebraska-Kansas region (MINK, Easterling *et al.* 1991) of the USA.

High resolution GCM's (Houghton *et al.* 1990, 1992) indicate that the set of GH scenarios employed here may need expansion; for example, the UKMO high resolution model (2.5 x 3.75 ) predicts that precipitation may decrease by 30-60% during the wet season and 0-50% during the dry season, with temperature increased by 2-4 C for both seasons. The medium sensitivity GH3d scenario best match the high resolution UKMO 2xCO<sub>2</sub> temperature increase. Our scenarios include an increase of precipitation rather than a decrease; this difference is not so important for the dry season scenarios, but may become important for the wet season scenarios (e.g. GH3w). Rainfall decreases could be incorporated in an expanded set of plausible scenarios. However, it should be emphasized that we are not using the GCM predictions to drive the crop models but as input to the development of a set



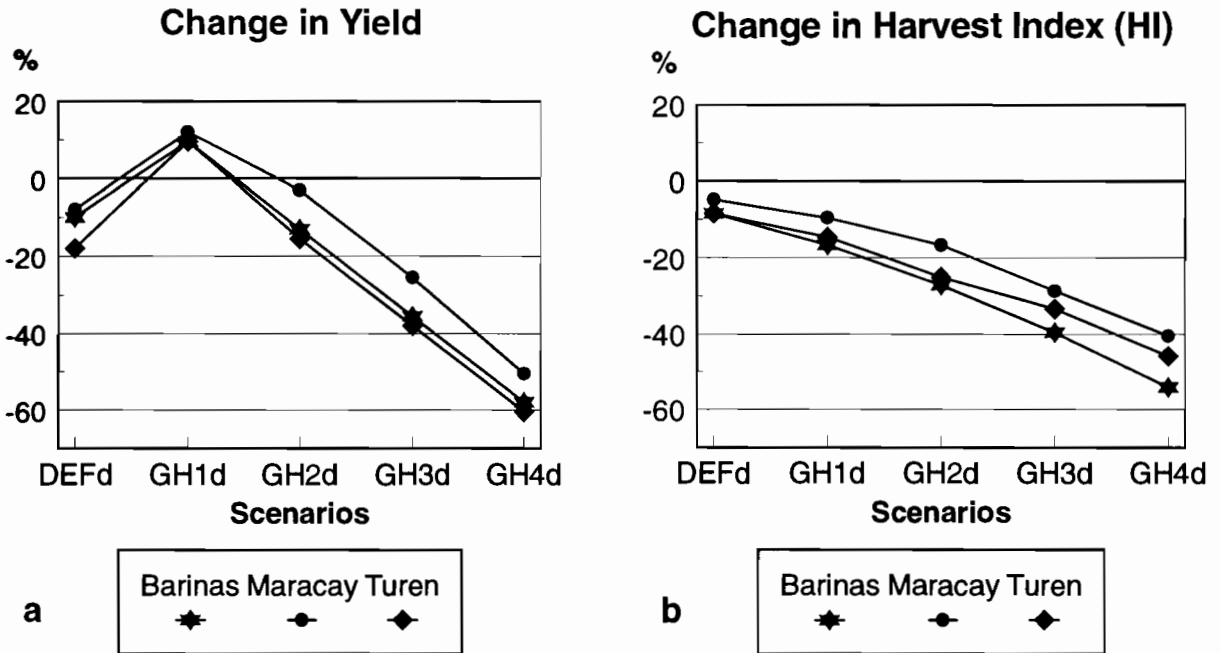
**Figure 3.** Impact of climate change, caused by the enhanced greenhouse effect and deforestation, on the yield of maize at Barinas, Turén, and Yaritagua. Yield changes in % of average (a) baseline climate years and of lower than average rainfall (b) baseline climate years.

**Effects on maize kernels**  
**Average over all sites**  
**Average and dry baseline years**



**Figure 4.** Impact of climate change, caused by the enhanced greenhouse effect and deforestation, on the number (a) and weight (b) of maize kernels. Changes in % of average baseline climate years and of lower than average rainfall (dry) baseline climate years.

**Effects on black bean**



**Figure 5.** Impact of climate change, caused by the enhanced greenhouse effect and deforestation, on the yield (a) and harvest index (b) of bean at Barinas, Turen and Maracay. Changes in % of average of five baseline years.

of plausible scenarios which could bound the range of potential crop responses to climate change.

The sites examined here are important representatives of maize and bean cultivation in Venezuela, but they do not account for all producing areas in the country. Extrapolation to larger spatial scales requires examination of a multitude of soil-climate combinations. Computer simulation runs to cover a larger number of sites in the Llanos region are currently underway in the PAN-EARTH project.

Expanding the assessment to other crops would contribute to a more comprehensive assessment. Unfortunately, models and data for calibration are not readily available for other important crops in Venezuela.

The social and economic implications of the potential impacts of global climate change on yield of staple crops have not been the emphasis of this case study. However, relationships between agricultural policy and impacts of global change need to be analyzed (e.g., Tolba 1991, Alcamo *et al.* 1994). Awareness of potential effects of climate change could help to plan and implement policies that could allow food production to meet the long term demand.

## ACKNOWLEDGEMENTS

We wish to thank many institutions and researchers which participated in this effort: Rigoberto Andressen (Universidad de Los Andes and Center for Tropical Climatology) and Alan Robock (University of Maryland), for scenario development; Juan Comerma and Evelyn Bisbal (FONAIAP) for support on model calibration and agricultural data; Franklyn Mendez (FONAIAP) and Claudio Caponi (MARNR), for weather data; Wendell Cropper (University of Florida) for assistance in using the CERES-Maize model; Gerrit Hoogenboom (University of Georgia) and Jeff White (CIAT, Cali Colombia) for technical guidance on BEANGRO model calibration; Maria Zuvia and Jean Hetier (ORSTOM-ULA), for assistance on soil

information. Special thanks go to the participants in the PAN-EARTH workshops. Several sources of funding made the Venezuela Case Study possible: CONICIT, FUNDAYACUCHO, CDCHT-ULA and the Rockefeller Brothers Fund.

## LITERATURE CITED

- ADAMS, R.M.; C. ROSENZWEIG, R.M. PEART, J.T. RITCHIE, B. MCCARL, J.D. GLYER, R.B. CURRY, J.W. JONES, K.J. BOOTE, and L.H. ALLEN Jr. 1990. Global climate change and US agriculture. *Nature* 345:219-224.
- ALCAMO, J., G.J. van den BORN, A.F. BOUWMAN, B.J. de HAAN, K. KLEIN GOLDEWIJK, O. KLEPPER, J. KRABEC, R. LEEMANS, J.G.J. OLIVIER, A.M.C. TOET, H.J.M. de VRIES, and H.J. van der WOERD. 1994. Modeling the Global Society-Biosphere-Climate System: Part 2: Computed Scenarios. *Water, Air, and Soil Pollution* 76:37-78.
- ANDRESSEN, R. 1989. Overview of Venezuela Climate, pp 14-17. In M.A. Harwell and M.F. Acevedo, eds. PAN EARTH/FONAIAP Workshop on Crop Model Training and Calibration, PAN-EARTH Project, Venezuela Case Study, Workshop Report. Maracay, Venezuela. November 13-16. 37 pp. [Available from RSMAS Program on Global Change, University of Miami, Miami, FL].
- AVILAN, J., and H. EDEN. 1987. Sistemas y regiones agrícolas de Venezuela. Three vols. MAC-Fundación POLAR. Caracas, Venezuela. 172 pp. [Available from Ministerio de Agricultura y Cría, Caracas, Venezuela].
- BAZZAZ, F.A. 1990. The response of natural ecosystems to the rising global CO<sub>2</sub> levels. *Annual Review of Ecology and Systematics* 21:167-196.
- BOWEN, W.T., J.W. JONES, R.J. CARSKY, and J.O. QUINTANA. 1993. Evaluation of the nitrogen submodel of CERES-Maize following legume green manure incorporation. *Agronomy Journal* 85:153-159.
- COMERMA, J. 1986. The use of simulation models for agrotechnology transfer in Venezuela. In *International Congress on Soils*, Hamburg 1986, 14 pp. [Available from FONAIAP, Instituto de Investigaciones Agrícolas Generales, Maracay, Venezuela].
- COMERMA, J. 1989. FONAIAP use of IBSNAT Methodology, pp 8-12. In M.A. Harwell and M.F. Acevedo, eds. PAN-EARTH/FONAIAP Workshop on Crop Model Training and Calibration, PAN-EARTH Project, Venezuela Case Study, Workshop Report. Maracay, Venezuela. November 13-16 1989. 37 pp. [Available from RSMAS Program on Global Change, University of Miami, Miami FL].

- CURRY, R.B., R.M. PEART, J.W. JONES, K.J. BOOTE, and L.H. ALLEN. 1990. Simulation as a tool for analyzing crop response to climate change. *Transactions ASAE* 33(3):981-990.
- DI. AZ. S., J.P. GRIME, J. HARRIS, and E. McPHERSON. 1993. Evidence of a feedback mechanism limiting plant response to elevated carbon dioxide. *Nature* 364:616-617.
- E. ASTERLING. W.E., M.S. MCKENNEY, N.J. ROSENBERG, and K.M. LEMON. 1991. Processes for identifying regional influences of and responses to increasing atmospheric CO<sub>2</sub> and climate change: The MINK Project. Report IIB. A farm-level simulation of the effects of climate change on crop production in the MINK region. 222 pp. US Department of Energy. Washington DC.
- FAJER, E.D., and F.A. BAZZAZ. 1992. Is carbon dioxide a 'good' greenhouse gas? Effects of increasing carbon dioxide on ecological systems. *Global Environmental Change* 2:301-310.
- HANSEN, J., A. LACIS, D. RIND, G. RUSSELL, P. STONE, I. FUNG, R. RUEDY, and J. LERNER. 1984. Climate sensitivity: analysis of feedback mechanisms. pp 130-163. In J. Hansen and T. Takahashi, eds. *Climate Processes and Climate Sensitivity*. American Geophysical Union, Washington, DC.
- HARWELL, M.A. 1993. Assessing the effects of global climate change: the PAN-EARTH project series. *Climatic Change* 23:287-292.
- HETIER, J.M., G. SARMIENTO, T. ALDANA, M. ZUVIA, D. ACEVEDO, and J.M. THIÉRY. 1989. The fate of nitrogen under maize and pasture cultivated on an alfisol in the western llanos savannas, Venezuela. *Plant and Soil* 114:295-302.
- HOOGENBOOM, G., J. WHITE, J.W. JONES, and K.J. BOOTE. 1991. Beangro V1.00 Dry Bean Crop Growth Simulation Model. User's Guide. Agricultural Engineering Department. University of Florida, Gainesville.
- HOOGENBOOM, G., G.Y. TSUJI, J.W. JONES, U. SINGH, D.C. GODWIN, N.B. PICKERING, and R.B. CURRY. (In press). A decision support system to study climate change impacts on crop production. In C. Rosenzweig, S. Hollinger, J.W. Jones and L. Harper, eds. *Climate Change and International Impacts*. In press. American Society of Agronomy Special Publication. Madison, Wisconsin.
- HOUGHTON, J.T., G.J. JENKINS, and J.J. EPHRAUMS, eds. 1990. *Climate Change. The IPCC Scientific Assessment*. Cambridge University Press, Cambridge, UK. 365 pp.
- HOUGHTON, J.T., B.A. CALLANDER, and S.K. VARNEY, eds. 1992. *Climate Change 1992. The Supplementary Report to the IPCC Scientific Assessment*. Cambridge University Press, Cambridge, UK. 200 pp.
- (IBSNAT) INTERNATIONAL BENCHMARK SITES FOR AGROTECHNOLOGY TRANSFER. 1990. Network Report, 1987-1990. 55 pp. [Available from Dept. of Agronomy and Soil Science, College of Tropical Agriculture and Human Resources, University of Hawaii, Honolulu, HI].
- (IBSNAT) INTERNATIONAL BENCHMARK SITES FOR AGROTECHNOLOGY TRANSFER. 1988. *Experimental Design and Data Collection Procedures for IBSNAT: The Minimum Data Set for System Analysis and Crop Simulation*. Technical Report 1. Third Edition Revised. 77 pp. [Available from Dept. of Agronomy and Soil Science, College of Tropical Agriculture and Human Resources, University of Hawaii, Honolulu, HI].
- IDSO, K.E., and S.B. IDSO. 1994. Plant responses to atmospheric CO<sub>2</sub> enrichment in the face of environmental constraints: a review of the past 10 years' research. *Agricultural and Forest Meteorology* 69:153-203.
- JAIMEZ, R., G. TONELLA, and M.F. ACEVEDO. 1993. Modelando el impacto de cambios climáticos sobre la producción de caraota en algunas localidades del Centro-Occidente de Venezuela. *Revista Forestal Latinoamericana* 13:9-38.
- JONES, C.A., and J. R. KINIRY, eds. 1986. *CERES-Maize: A Simulation Model of Maize Growth and Development*. Texas A&M University Press. College Station, Texas. 193 pp.
- LIU, W.T.H., D.M. BOTNER, and C.M. SAKAMOTO. 1989. Application of CERES-Maize model to yield prediction of a Brazilian maize hybrid. *Agriculture and Forest Meteorology* 45:299-312.
- (MAC) MINISTERIO DE AGRICULTURA Y CRÍA, VENEZUELA. 1993. Memoria y Cuenta. Chapter I. 217 pp. [Available from Ministerio de Agricultura y Cría, Caracas, Venezuela].
- MAYTÍN, C.E., M.F. ACEVEDO, R. JAIMEZ, R. ANDRESSEN, M.A. HARWELL, A. ROBOCK, and A. AZÓCAR. 1995. Potential effects of global climatic change on the phenology and yield of maize in Venezuela. *Climatic Change* 29:189-211.
- PEART, R.M., J.W. JONES, R.B. CURRY, K. BOOTE, and L.H. ALLEN Jr. 1989. Impact of Climate Change on Crop Yield in the Southeastern USA: A simulation study. pp 2-1 to 2-54. In J.B. Smith and D.A. Tirpak, eds. *The Potential Effects of Global Climate Change on the United States, Appendix C-1. Agriculture*, US Environmental Protection Agency, Washington DC.
- RIEHL, H. 1979. *Climate and Weather in the Tropics*. Academic Press, New York, 611 pp.
- RITCHIE, J.T., U. SINGH, D.C. GODWIN, and L. HUNT. 1989a. *A user's guide to CERES maize- V2.10*. 86 pp. International Fertilizer Development Center, Muscle Shoals, Alabama.

- RITCHIE, J.T., B.D. BAER, and T.Y. CHOU. 1989b. Effect of global climate change on agriculture: Great Lakes region. pp 1-1 to 1-30. In J.B. Smith and D.A. Tirpak, eds. *The Potential Effects of Global Climate Change on the United States*. Appendix C-1 Agriculture. US Environmental Protection Agency. Washington, DC
- ROBOCK, A., R. TURCO, M.A. HARWELL, T.P. ACKERMAN, R. ANDRESSEN, H-S. CHANG, and M.V.K. SIVAKUMAR. 1993. Use of general circulation model output in the creation of climate change scenarios for impact analysis. *Climatic Change* 23:293-335.
- ROSE, E. 1989. Direct (physiological) effects of increasing CO<sub>2</sub> on crop plants and their interactions with indirect (climatic) effects. pp 7-1 to 7-37 In J.B. Smith and D.A. Tirpak, eds. *The Potential Effects of Global Climate Change on the United States*. Appendix C-2 Agriculture. US Environmental Protection Agency. Washington, DC.
- ROSENZWEIG, C. 1989. Potential effects of climate change on agricultural production in the Great Plains: A simulation study. pp 3-2 to 3-43. In J.B. Smith and D.A. Tirpak, eds. *The Potential Effects of Global Climate Change on the United States*. Appendix C-1 Agriculture. US Environmental Protection Agency. Washington, DC
- ROSENZWEIG, C. 1990. Crop response to climate change in the Southern Great Plains: A simulation study. *The Professional Geographer* 42(1):20-37.
- SCHLESINGER, M.E., and Z.-C. ZHAO. 1989. Seasonal climate changes induced by doubled CO<sub>2</sub> as simulated by the OSU atmospheric GCM/mixed-layer ocean model. *Journal of Climate* 2:459-495.
- SHUKLA, J., C. NOBRE, and P. SELLERS. 1990. Amazon deforestation and climate change. *Science* 247:1322-1325.
- SULZMAN, E.W., K.A. POIANI and T.G.F. KITTEL. 1995. Modeling Human-Induced Climatic Change: A Summary for Environmental Managers. *Environmental Management* 19(2):197-224.
- TOLBA, M.K. 1991. Preparing for global and regional effects of climate change. *The Environmental Professional* 13:2-7.
- WETHERALD, R.T., and S. MANABE. 1986. An investigation of cloud cover change in response to thermal forcing. *Climatic Change* 8:5-23.
- WILLIAMS, J.R., C.A. JONES, and P.T. DYKE. 1990. The EPIC model. pp 3-92. In A.N. Sharpley and J.R. Williams, eds. EPIC- Erosion/Productivity Impact Calculator: 1. Model Documentation. US Department of Agriculture Technical Bulletin N° 1768. 235 pp. USDA-ARS, Temple, Texas.
- WILSON, C., and B. MITCHELL. 1987. A CO<sub>2</sub> climate sensitivity experiment with a global climate model including a simple ocean. *Journal of Geophysical Research* 92(13):315-343.