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Climate change impact uncertainties for maize in Panama: Farm information, climate projections, and yield sensitivities

Alex C. Ruane[a,b,*], L. DeWayne Cecil[c], Radley M. Horton[b,a], Román Gordón[d], Raymond McCollum[e], Douglas Brown[e], Brian Killough[f], Richard Goldberg[b], Adam P. Greeley[b], Cynthia Rosenzweig[a,b]

[a] NASA Goddard Institute for Space Studies, New York, NY, USA
[b] Columbia University Center for Climate Systems Research, New York, NY, USA
[c] NOAA, National Climatic Data Center, Salt Lake City, UT, USA
[d] Instituto de Investigación Agropecuaria de Panamá, Los Santos, Panama
[e] Booze-Allen-Hamilton, Norfolk, VA, USA
[f] NASA Langley Research Center, Langley, VA, USA

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ABSTRACT

We present results from a pilot project to characterize and bound multi-disciplinary uncertainties around the assessment of maize (*Zea mays*) production impacts using the CERES-Maize crop model in a climate-sensitive region with a variety of farming systems (Panama). Segunda coa (autumn) maize yield in Panama currently suffers occasionally from high water stress at the end of the growing season, however under future climate conditions warmer temperatures accelerate crop maturation and elevated CO_2 concentrations improve water retention. This combination reduces end-of-season water stresses and eventually leads to small mean yield gains according to median projections, although accelerated maturation reduces yields in seasons with low water stresses. Calibrations of cultivar traits, soil profile, and fertilizer amounts are most important for representing baseline yields, however sensitivity to all management factors are reduced in an assessment of future yield changes (most dramatically for fertilizers), suggesting that yield changes may be more generalizable than absolute yields.Uncertainty around GCMs' projected changes in rainfall gain in importance throughout the century, with yield changes strongly correlated with growing season rainfall totals. Climate changes are expected to be obscured by the large interannual variations in Panamanian climate that will continue to be the dominant influence on seasonal maize yield into the coming decades. The relatively high (A2) and low (B1) emissions scenarios show little difference in their impact on future maize yields until the end of the century. Uncertainties related to the sensitivity of CERES-Maize to carbon dioxide concentrations have a substantial influence on projected changes, and remain a significant obstacle to climate change impacts assessment. Finally, an investigation into the potential of simple statistical yield emulators based upon key climate variables characterizes the important uncertainties behind the selection of climate change metrics and their performance against more complex process-based crop model simulations, revealing a danger in relying only on long-term mean quantities for crop impact assessment.

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1. Introduction

The generation of decision support systems for climate change impacts relies on a long series of processes from data collection, data processing and numerical simulations, analysis of results, and interpretation for stakeholder use. Uncertainties exist in each process, and must be quantified to enable stakeholders to manage risk in designing adaptation strategies placing climate uncertainties in the proper background of regional and management variability (Iglesias et al., 2010; White et al., 2011). For each region and agricultural system it is likely that several sources of uncertainty act as crucial bottlenecks with larger influence on the final messages received by stakeholders, and therefore locating critical pieces of information can dramatically improve impacts assessment. This study examines a pilot climate change impacts for decision support process from start to finish, identifying these various sources of uncertainty and isolating areas where further research could dramatically improve outcomes.

A Mesoamerican pilot location for agricultural impacts was selected to directly inform two ongoing projects in the region. The NASA/USAID SERVIR project (http://www.servir.net last accessed

* Corresponding author at: 2880 Broadway, New York, NY 10025, USA. Tel.: +1 212 678 5640; fax: +1 212 678 5648.
E-mail address: alexander.c.ruane@nasa.gov (A.C. Ruane).

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June 29, 2011; Graves et al., 2005) delivers state-of-the-art NASA observations to Mesoamerican users for applications including agriculture, water resources, health, and flash-flood relief. A NASA GISS/Columbia University/University of Florida project is also underway to provide decision support for climate change impacts on agriculture across Central America and the Southeast United States using dynamic biophysical crop models, with results designed to be potentially included in SERVIR's online resources. We selected maize (*Zea mays*), a major commodity and important source of food in Mesoamerica, as the crop to be investigated, and a range of climate periods to be relevant to ongoing planning of agricultural policy and infrastructure as well as to provide longer-term scenarios where the climate change signal is more clearly separated from natural interannual to interdecadal variability. Giorgi (2006) identified the Central American region as a location where rainfall variability changes pose a substantial risk (more so than mean climate changes), although changes in both rainfall's mean and variability are projected to be more significant in the November–April dry (and less agriculturally important) season not analyzed here.

Dynamic process-based crop models resolve plant and environmental processes relevant to crop growth and are rooted in physical responses dependent on developmental stage and crop stresses that may interact in a non-linear manner. Unlike simple statistical regression models, process-based crop models are capable of simulating the impacts of climate conditions outside of observed historical ranges, including the effects of high carbon dioxide concentration ([CO_2]) environments. Resolution of these processes comes at the cost of spatial coverage – these crop models are run at a representative field rather than directly representing a wider region – and an onerous requirement of input data (described in the next section). These data are simply not available in many important agricultural regions or across the wide diversity of farming systems in many developing areas, but these regions still need a strategy to address climate vulnerabilities. This study examines whether the types and amount of required input data may depend on the application, as the crop model does not necessarily need to exactly capture baseline yields in order to investigate how yields respond to climate changes.

This work also explores the potential of future yield changes to be summarized by a strong response to projections of a small number of key climate change metrics. Recent studies have demonstrated the utility of visualizing climate impacts response surfaces based upon projected changes in temperature and rainfall across a wide range of plausible climate conditions to allow a rapid assessment of key sensitivities (e.g., Jones, 2000; Scholze et al., 2006; Morse et al., 2009; Fronzek et al., 2010; Räisänen and Ruokalainen, 2006), however non-linearities in the biophysical response to climate factors can lead to significant biases in some cases (Hansen et al., 2006; Schlenker and Roberts, 2006, 2009). The precision of impacts response surfaces regressed from crop model simulations is likely to depend on the crop, region, and degree to which yield changes are sensitive to particular climatic variables.

The results presented are a useful pilot exploration of uncertainty for the Agricultural Model Intercomparison and Improvement Project (AgMIP; Rosenzweig et al., 2012; this issue), which seeks to connect climate scientists, crop modelers, agricultural economics modelers, and information technology specialists to simulate agricultural production across the world's important agricultural regions for analysis of the linked economic impacts of climate change. The availability of high-quality soil, weather, cultivar, and agricultural management data reduces many of the uncertainties in the simulation of climate impacts on crop production, but are not always available in data-scarce areas. In addition, homogeneous areas with more intensive management, modern cultivars, and heavy use of mechanical equipment are more suited to crop model simulations based upon a single representative farm. This study examines the uncertainties that may be reduced if crop models are granted access to farm-level information and climate records to underscore the importance of local involvement in AgMIP and other crop modeling applications, and also to explore the transferability of climate impact projections from one particular farming system to another in a region with diverse agricultural practices.

2. Material and methods

2.1. The CERES-Maize crop model

Crop model simulations were conducted with the Crop Estimation through Resource and Environment Synthesis crop model (CERES-Maize), a component of the Decision Support System for Agrotechnology Transfer (DSSAT v4.5.0.047; Jones et al., 2003; Hoogenboom et al., 2010). DSSAT is a family of crop models that simulate daily crop development and complex interactions with the farm-level environment using biophysical processes that facilitate application outside of observed climate conditions. These crop model simulations require local weather data (daily rainfall, minimum and maximum temperatures, and solar radiation), a detailed soil profile, genetic coefficients describing the specific maize cultivar, and crop-management practices (e.g. planting dates and practices; irrigation and fertilizer applications). As of this writing only a few published studies could be identified that document maize model applications in Mesoamerica (e.g. Conde et al., 1997, in Mexico; Maytín et al., 1995; Jones and Thornton, 2003, using generalized cultivars and management for gridded assessment of all of Latin America), but these studies do not focus on uncertainty analysis and not all include [CO_2] effects. Crop model applications are also conducted at some national meteorological or agricultural agencies; however formal publication and documentation were not readily located.

2.2. Farm-level data collection and calibration

Panama was selected as a Mesoamerican pilot location due to its hosting of the headquarters for SERVIR Mesoamerica at the Water Center for the Humid Tropics, Latin America, and the Caribbean (CATHALAC) in Clayton, Panama. While dominant throughout Northern Mesoamerica (Nicaragua and north), maize production lags behind rice production in Panama but remains a prominent rainfed crop (USDA FAS, available at http://www.fas.usda.gov/psdonline, last accessed June 30th, 2011). Panamanian maize cultivation is concentrated on the eastern portion of the Azuero Peninsula that extends into the Pacific from the South of the country (Fig. 1a). To simulate this region, a representative weather series at Los Santos (7.95°N, 80.42°W) was provided by the Panamanian Electric Transmission Company (ETESA),[1] and a Panamanian Cambisol soil profile was drawn from the WISE database (Batjes and Bridges, 1994) to match the Harmonized World Soil Database (FAO, 2009) reported conditions (Fig. 1b).

Daily rainfall, maximum and minimum temperatures, and sunshine hours were collected for 1980–2009 to gauge baseline climate without being overly obscured by shorter term natural modes of variability (WMO, 1989; Guttman, 1989). Sunshine hours were converted to daily solar radiation and data gaps were filled in using the WGEN-based weather generator (Richardson and Wright, 1984) included in Weatherman (a component of DSSAT). Fig. 2 presents

[1] Global station datasets proved to have questionable rainfall totals and limited spatial coverage for our desired applications.