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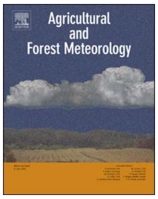

The effects of projected climate and climate extremes on a winter and summer crop in the southeast USA

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ABSTRACT

In this study, we explored how changing climate conditions in the 20th and 21st century affect summer and winter crop yields the southeast United States. An ensemble of 10 global circulation models (GCMs) were utilized and the uncertainties associated to their estimates were calculated. The objectives of this study were to utilize historical and projected climate data to (*i*) analyse historical and projected precipitation and temperature separately for a winter and a summer crop; (*ii*) evaluate how these climate factors impact the crop yield and the water use; (*iii*) quantify for the two crops, and for vegetative vs. reproductive stages, the impacts of climate extremes on crop yield and water use. The daily weather data for both historical and projected periods were obtained from the Multivariate Adaptive Constructed Analogs (MACA) downscaled Coupled Model Intercomparison Project Phase 5 (CMIP5) datasets. A series of 16 climate extremes indices mostly selected from the Expert Team on Climate Change Detection and Indices (ETCCDI) was calculated using the MACA downscaled CMIP5 data. The Decision Support System for Agrotechnology Transfer (DSSAT) model was used to simulate the effects of climate on a summer crop (maize, using the CERES-Maize model) and a winter crop (wheat, using the CERES-Wheat model) crop on a silty-clay and on a sandy soil during the historical baseline (1950–1999) and the projected (2006–2055) periods. Overall, the decadal crop-specific growing season temperature trend showed warming of the southeast with little variability across the climate models for the baseline and an increase uncertainty for future conditions. For each 1 °C the simulated maize yield would decrease by 4.6% across the different climate projections, while wheat would be reduced by 3.8%. Water use efficiency decreased under future projections by 2.7% on a silty-clay soil, independently of the winter/summer crop, but on a sandy soil the decrease was 4% for maize and 1.7% for wheat. The impacts of projected temperature and rainfall change will be different for a winter than for a summer crop depending on the type of soil on which the crop is grown.

1. Introduction

The rapid increase of world's population and its projected trend associated with an increase in global food demand make agriculture to face a dilemma of producing more food on the same (or even less) cultivated areas (Foley et al., 2011). Failing to match food production with the global food demand might cause increase in food prices leading to an increase in poverty rates and hunger (Godfray et al., 2010). In addition, crop production should be obtained in a sustainable way that is without polluting the environment but without reducing the farmers' income.

Agriculture is very sensitive to both climate variability and change and therefore any adverse impact due to climate will increase the vulnerability of agricultural production. The growing season (defined as the period between sowing and harvest) temperature, rainfall, and the CO_2 concentrations affect positively/negatively crop growth and development. Many studies have been conducted assessing the effects of individual climate parameters, or a combination of them on crop growth, development, and yield (Amthor, 2001; Sadras and Monzon, 2006; Kimball, 2010; Allen et al., 2011; Hatfield et al., 2011). The southeast USA has a very heterogeneous crop production and agriculture is among the major economic contributors to the region contributing to more than 17% the total annual USA agricultural production (Ingram et al., 2013). The projected future changes of droughts, and heat stress during summer months will affect agriculture outputs in the region (Ingram et al., 2013).The climatic effects on crops can be quantified using crop growth models (CSM) as they simulate the daily growth, development and final yield as affected by weather, soil, crop characteristics, and agronomic management; and CSM can be used to extrapolate such interactions beyond a single year and a single

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experimental site (Jones et al., 2003).

Global Climate Models (GCMs) have been used to study the impacts of projected climate for a specific agricultural area. Their resolutions are rather coarse and to provide a better application to local conditions they have been downscaled at finer scales using either a statistical or a dynamic downscaling (Fowler et al., 2007). However, GCMs might contain biases in terms of specific temperature extremes or rainfall patterns that could affect their use in CSM and bias the simulated yield (Cammarano et al., 2013; Carbone et al., 2003; Hansen and Jones, 2000). Nevertheless, when a sufficient big ensemble of GCMs are used as input into the CSM the problem of bias due to a single or few GCMs would be minimized because the uncertainty around such estimates can be quantified (Tebaldi and Knutti, 2007).

Karmalkar and Bradley (2017) pointed out that the estimated impacts of temperature will change according to the level of resolution studies, e.g. from the globe to regional. For climate studies related to agricultural production the three main issues to consider when analysing the impacts of climate on crop production are: (i) the scale (global vs. local); (ii) the growth stage of the crop, because some temperature threshold might be harmful at a particular stage but not at another; and (iii) the time-frame (annual vs. growing season) because it would be more useful to look at the growing season climatology rather than the calendar year. The latter point means that winter and/or summer crops will be impacted differently by climate variability and climate change. Folberth et al. (2016) showed that the type of soil can outweigh and buffer the effects of climate variability like changes in rainfall and temperature. Their study was done at a global level and they concluded that any recommendations in terms of adaptations should consider such issue.

The quantification of projected climate impacts on agricultural production are an important step to make when choosing adaptation measures for sustainable food supply. In this study, we will explore how changing climate conditions in the 20th and 21st century affect summer and winter crop yields in the southeast United States on two contrasting soil types. The approach used an ensemble of GCMs and the uncertainties associated to their estimates were determined.

The objectives of this study were to utilize historical and projected climate data to (*i*) analyse historical and projected precipitation and temperature separately for a winter and a summer crop; (*ii*) evaluate how these climate factors impact the production and the water use of the two crops; (*iii*) quantify for the two crops, and for vegetative vs. reproductive stages the impacts of climate extremes on crop yield and water use.

2. Materials and methods

2.1. Weather data

The weather data used in this study were retrieved from the Multivariate Adaptive Constructed Analogs (MACA) downscaled CMIP5 datasets (Abatzoglou, 2011), available at http://maca.northwestknowledge.net/data_portal.php. MACA is a statistical downscaling method which used a training dataset based on observed meteorological data to correct historical and projected biases and match the spatial patterns in climate model outputs (Abatzoglou and Brown, 2012). The MACA method downscaled 20 Global Climate Models (GCM) belonging to the Coupled Model Inter-Comparison Project 5 (CMIP5) on the historical weather data series (1950–2005) and on the future Representative Concentration Pathways (RCPs) 4.5 and 8.5 (2006–2099). The CO_2 concentration considered for each period was 350 ppm for the baseline, 538 ppm and 936 ppm for the RCP4.5 and RCP8.5, respectively. For this study we used the following daily variables: daily maximum temperature (T*max*); daily minimum temperature (T*min*); average daily rainfall (*prcp*); and average daily downward shortwave radiation (*rsds*). This study used the newest version of the MACA downscaled CMIP5 datasets: MACA-v2-METDATA. This dataset has been evaluated with observed data in the southeast USA through the PINEMAP project (PineMAP, 2017). We utilized the dataset for the historical period and the two RCPs, 4.5 and 8.5, respectively. The GCMs chosen were reported in Table 1 along with the associated CO_2 concentration considered for each RCP. The area considered in this study spanned over 5 States located in the southeast USA: Alabama, Florida, Georgia, North Carolina, South Carolina.

Table 1
List of the Global Climate Models (GCMs) used in the study as both historical dataset, RCP4.5 and RCP8.5.

GCM	GCM	Baseline	Representative Concentration Pathways (RCPs)	
ID	#	*Historical*	*RCP4.5*	*RC8.5*
bcc-csm1-1-m	1	350	538	936
CanESM2	2	350	538	936
CCSM4	3	350	538	936
CNRM-CM5	4	350	538	936
CSIRO-Mk3-6-0	5	350	538	936
GFDL-ESM2M_	6	350	538	936
HadGEM2-ES365	7	350	538	936
IPSL-CM5A-MR	8	350	538	936
MIROC5	9	350	538	936
NorESM1-M	10	350	538	936

2.2. Climate indices

A series of 16 climate indices selected from the Expert Team on Climate Change Detection and Indices (ETCCDI, Zhang et al., 2011) was calculated using the MACA-v2-METDATA data (baseline, RCP 4.5 and RCP 8.5). The indices were calculated using daily data and split between sowing to anthesis and anthesis to maturity. This was done to separate the climate effect on the two major phenological stages which were flowering and grain filling. Specifically, the indices dealt with the effects of maximum and minimum temperature, and with the effects of rainfall intensity and duration. The thresholds for T*max* and T*min* used in the calculation of the indices was derived from published results were the effects of daily temperatures affecting crop growth, development and senescence rates on wheat and maize were analysed. For maize, the thresholds were T*min* < 8 °C and T*max* of > 34 °C. The former, caused a halt in maize development, the latter accelerated maize life cycle causing a shortening of grain-filling duration and a stop to crop growth (Lopez-Cedron et al., 2005). For wheat the thresholds were T*min* < 0 °C at which crop development stops and T*max* > 32 °C which caused heat stress and reduction in yield due to acceleration in senescence rates (Asseng et al., 2011; Porter and Gawith 1999). The indices were described in Table 2.

2.3. Crop simulation

The simulation of daily maize and wheat growth and development during the historical baseline (1950–1999) and the projected (2006–2055) periods were made using the DSSAT 4.5 (Decision Support System for Agrotechnology Transfer; Hoogenboom et al., 2010; Jones et al., 2003) CERES-Maize model and CERES-Wheat model, respectively. The DSSAT has been run and tested with experimental data worldwide for more than 20 years resulting in one of the most utilized crop models (Koo and Rivington, 2005). The modelling setup for this experiment is the same as the one described in Cammarano et al. (2013; Cammarano et al. (2013; 2016) and Tian et al. (2015), which has been well calibrated and validated using trial data in the southeast USA. The only difference is that the CERES-Wheat is used instead of the APSIM-NWheat 1.55s, and the crop parameters for the CERES-Wheat were obtained from the work of Tapley et al. (2012). The maize cultivar used in the simulation was a medium season hybrid, while for wheat it was