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Assessment of irrigated maize yield response to climate change scenarios in Portugal

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ABSTRACT

Maize is an important crop for the Portuguese agricultural sector. Future climate change, with warmer and dryer conditions in this Mediterranean environment, will challenge this high-water demanding crop. The present study aims at assessing the response of maize yield, growth cycle, seasonal water input and daily water productivity (DWP) to climate change, and analyse water-yield relations. For this purpose, two process-based crop models are used (STICS and AquaCrop) and were validated in simulating irrigated maize yields in Central Portugal (Ribatejo) by using regional statistics (1986–2005). Both models show an overall agreement in their outputs. The 2-model mean outputs are considered under future climate projections (2021–2080; RCP4.5 and 8.5), using the global/regional climate model chain M-MPI-ESM-LR/SMHI-RCA4. The most significant reductions on maize yield (−17%), growth cycle (−12%) and DWP (−19%) are observed for 2061–2080 under RCP8.5, with a noticeable decrease of seasonal water input (−9%) during 2041–2060. Decreased DWP is largely due to significant yield reduction, with limited benefit of atmospheric CO_2 enrichment. A water-yield relation analysis highlights that an increase of 2–14% in irrigation for future scenarios (compared to 1986–2005) might be a suitable strategy to mitigate yield reduction, despite substantially lower DWP (down to −23%). These findings demonstrate that our model approach can be used as a decision support tool by Portuguese farmers, particularly in optimizing maize production under changing climates.

1. Introduction

Crop production systems are often largely controlled by environmental factors, thus being vulnerable to climate change (IPCC, 2013). Anthropogenic forcing, leading to continuous rise of greenhouse gas (GHG) atmospheric concentrations, is expected to alter regional temperature and precipitation patterns, also contributing to higher risks of extreme weather events and climate irregularity (IPCC, 2013), with obvious implications on crops (Porter and Semenov, 2005). Maize (*Zea mays* L.) is a main food crop in the world and Europe is one of the most productive regions (Olesen et al., 2011). Assessments of maize responses to past changing climatic conditions generally point to an increased risk of yield reduction for Southern Europe and Mediterranean regions (Olesen et al., 2011; Supit et al., 2010; Wolf and Vandiepen, 1995). In the recent-past, irrigation strategies has been critical to stabilize/maximize yields in many regions worldwide, such as in Mediterranean-type climatic regions, where precipitation is scarce during the maize growing season. Crop water stress hampering physiologic processes (e.g. canopy cover expansion and stomatal functions) is expected to be enhanced by future warmer and drier climates, requiring more irrigation to mitigate potential yield reductions (Doll, 2002; Fischer et al., 2007; Wolf and Vandiepen, 1995).

Portugal, located in Southwestern Europe, features typical Mediterranean conditions. Maize has the largest area amongst annual crops, playing a key role in the Portuguese agri-food sector (Nóbrega, 2006). One of the most important maize growing regions is Ribatejo-Oeste (in Central Portugal, hereafter Ribatejo) (Fig. 1), having approximately ~30,000 ha of maize fields (ca. 35% of the total maize area in Portugal) (INE, 2015). The Ribatejo climate, characterized by very dry summers, does not naturally provide optimal conditions for a high water-demanding crop like maize, with a spring-summer growing season. Hence, almost all of the maize cultivated area (94%) is currently irrigated (INE, 2015).

According to the IPCC latest report (IPCC, 2013), southern Iberia (where Ribatejo is located) is projected to experience higher temperatures and lower precipitation in the future, which may bring new challenges for the regional sustainability of this crop. Fur-

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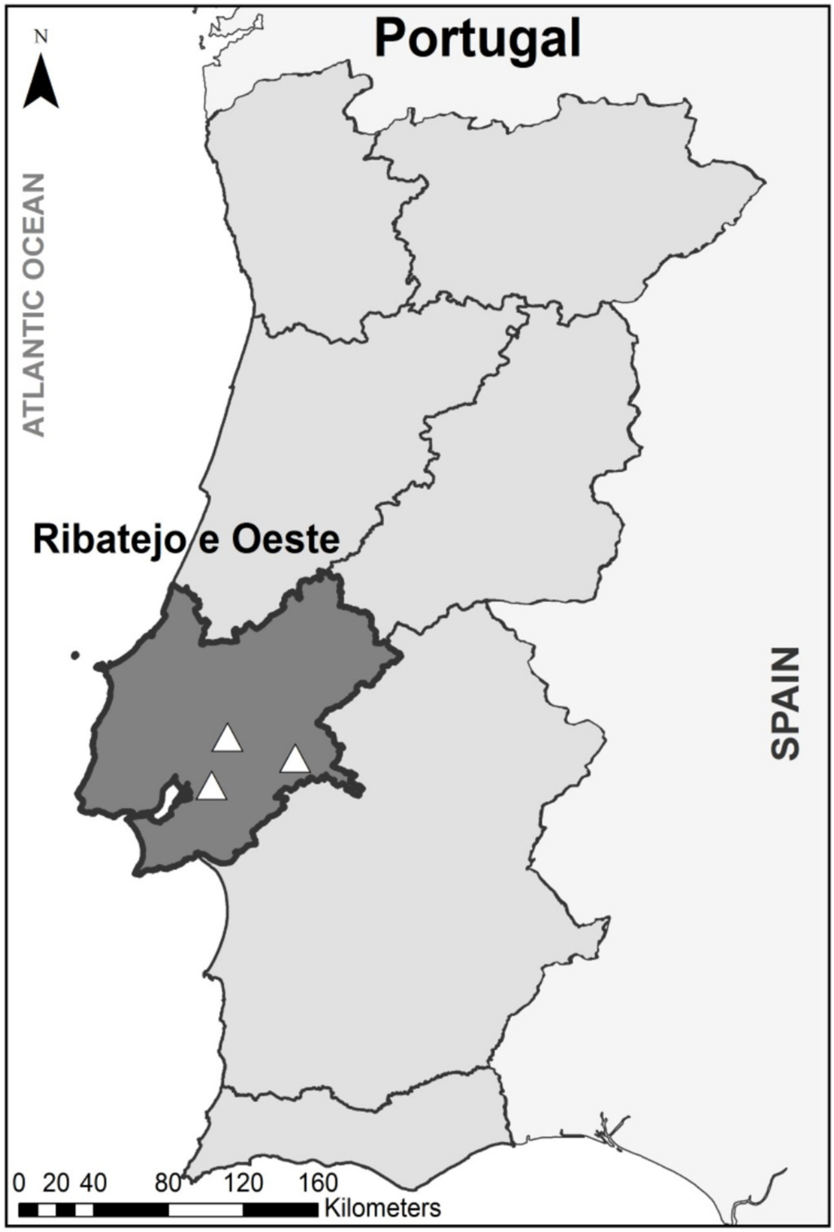

Fig. 1. Location of the three selected sites in Ribatejo, Portugal.

thermore, water availability for agricultural purposes is decreasing rapidly, as water demand by other socioeconomic sectors is also growing (Iglesias and Garrote, 2015; Iglesias et al., 2007). Maximizing water use efficiency (WUE) or water productivity (WP), i.e. the ratio of crop yield to transpiration-driven water uptake, is a plausible adaptation measure for stabilizing crop yields in the future (Zhang and Oweis, 1999). WP can also be defined based on the ratio of yield to the sum of precipitation and irrigation (Howell, 2001).

Therefore, it becomes necessary to analyse maize yield response to varying water supply in order to identify the most efficient irrigation scheduling (Afzal et al., 2016; Dagdelen et al., 2006; Farre and Faci, 2009; Katerji and Mastrorilli, 2009). In future climates, the established water-yield relations are susceptible to being changed. The enhanced CO_2 levels may trigger higher maize biomass accumulation and yields, particularly under crop water stress conditions, while it tends to reduce water demand by diminishing crop transpiration (Islam et al., 2012). Rising temperatures may accelerate crop phenological development rates and shorten growing season, along with intensified transpiration rates. The multiple interactions among climatic elements and crops require an integrated analysis. As such, to better evaluate crop responses to climate change, process-based crop models are becoming increasingly used tools (Kang et al., 2009).

Coupling crop models with climate change projections, generated by high resolution regional climate models, is a common approach. Crop models dynamically simulate crop responses to management practices (e.g. irrigation), soil properties (e.g. texture, depth), as well as crop physiological responses to atmospheric conditions (e.g. air temperature, precipitation and CO_2). Some examples of these models are STICS (Simulateur mulTIdisciplinaire pour les Cultures Standard) (Brisson et al., 2003) and AquaCrop (Steduto et al., 2009). These two crop models mainly differ in their growth module: STICS is a radiation-driven model, estimating daily biomass formation from canopy intercepted radiation (Brisson et al., 2009), whereas AquaCrop adopts a water-driven strategy, assuming a linear relationship between crop transpira-