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Climate change, effective water use for irrigation and adaptability of maize: A case study in southern Italy

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Climate change may lead to differences in the distribution of precipitation and to reduced water availability, with constraints on the cultivation of some crops. An analysis of vulnerability and of opportunities for adaptation is required for crops in areas where they are currently cultivated. The intra-specific biodiversity of crops is a significant resource for the adaptation of agriculture, but requires better knowledge of the responses of cultivars to environmental stressors. Simulation models of water flow in the soil-plant-atmosphere system can be coupled with future climate scenarios to describe the soil water regime, taking into account different irrigation scheduling options. The adaptive capacity of maize hybrids is evaluated in an irrigated district in Southern Italy. Two climate cases were studied: "reference" (1961–1990) and "future" (2021–2050). The model SWAP was run to determine the soil water balance for different irrigation levels. For each level the effectiveness of irrigation was evaluated by means of a performance indicator (IE). The Relative Evapotranspiration Deficit (RETD) was used as an indicator of water availability. The yield response to water availability of several maize hybrids was determined; their hydrologic requirements were thus defined and compared with the simulated values of RETD in response to climate and irrigation. Soil moisture regime and irrigation performance were also analysed. The adaptability of hybrids to the future water regime was assessed for different irrigation levels. The study indicated how, in the future climate case, the intra-specific crop biodiversity, in combination with cropping patterns better adapted to soil characteristics, may allow the current production system to be maintained.

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Symbols and abbreviations

Nomenclature

DAS	day after sowing
DOY	day of year
E_p	potential evaporation (mm d^{-1})
ET_{act}	cumulative actual crop evapotranspiration over the whole crop growth cycle (mm)
ET_{max}	cumulative maximum crop evapotranspiration over the whole crop growth cycle (mm)
ET_o	reference evapotranspiration (mm d^{-1}, mm)
ET_p	crop potential evapotranspiration (mm d^{-1})
H	soil water pressure head (cm)
h_{irr}	soil water pressure head value applied to simulate different irrigation schedules (cm)
IE	irrigation effectiveness (–)
IQR	inter quartile range (–)
Ir	seasonal total water applied for each irrigation case (mm)
K	hydraulic conductivity (cm d^{-1})
LAI	leaf area index (m^2 m^{-2})
MPA	medians of the probabilities of adaptation (–)
MPA_{hyb}	medians of the probabilities of adaptation of hybrids (–)
$MPA_{hyb\&soil}$	medians of the probabilities of adaptation for all combination of hybrids and soils (–)
PA	probability of adaptation (–)
RETD	Relative Evapotranspiration Deficit (–)
$RETD_{hyb}$	Hybrid-specific hydrological requirement (–)
S	water extraction rate by plant roots (cm^3 cm^{-3} d^{-1})
SMU	Soil Mapping Unit
STU	Soil Typological Unit
SWAP	Soil water plant atmosphere model
T_{act}	actual crop transpiration (mm d^{-1})
T_{act0}	cumulative actual crop transpiration over the whole crop growth cycle, with no irrigation (mm)
T_{actIr}	cumulative actual crop transpiration over the whole crop growth cycle, for each irrigation case (mm)
T_{pot}	potential crop transpiration (mm d^{-1})
Y_{act}	actual yield (t)
Y_{max}	maximum yield (t)
Yr	relative yield (–)
Yr_{adapt}	level of relative yield acceptable for adaptation
z_r	depth of the root zone (cm)
θ	volumetric soil water content (cm^3 cm^{-3})
α	function of soil water pressure head (–)

1. Introduction

The studies performed in the last decade on anthropogenic climate change across Europe show consistent projections of increases in temperature and different patterns of precipitation (Olesen et al., 2011). The 4th Report of the Intergovernmental Panel on Climate Change (IPCC, 2007) indicates that annual precipitation is likely to increase in most of Northern Europe and to decrease in most of the Mediterranean area. Furthermore the annual number of rainy days is very likely to decrease in the Mediterranean area (Field, Barros, Stocker, & Dahe, 2012). The latter represents an area of high vulnerability to future climate change (Giorgi & Lionello, 2008). Significant effects of climate change on both mean precipitation and variability, with relevant consequences on water availability and crop production, are reported in many studies (Giorgi & Lionello, 2008; Sheffield & Wood, 2008; Ulbrich et al., 2006). With increasing water scarcity, there is the need to optimise water use, mainly for irrigation purposes (Pereira, Cordery, & Iacovides, 2009). Thus, farmers should adopt improved irrigation management strategies, such as deficit irrigation schedules, to enhance water productivity. Efficient irrigation water use can be achieved through a combination of better soil and water management practices and better irrigation equipment (Knox, Kay & Weatherhead, 2012). In many European countries there has been a recent trend for cereal yields to plateau and for increased yield variability that might be related to recent climatic trends (Brisson et al., 2010; Olesen et al., 2011).

Maize (*Zea mays* L.) is the third most important cereal crop in the world after wheat and rice. It is one of the main cereals cultivated in Italy over an area of 826,000 ha with a total production of 63.5 Mt (ISTAT, 2013). It is a high input crop that requires large quantities of water and fertilisers. The large crop water demand for high productivity requires effective management of water resources. Maize is very sensitive to water deficit, therefore quantitative knowledge of crop response to limited water availability is important to improve productivity, and to compare with alternative cropping options (Payero, Melvin, Irmak, & Tarkalson, 2006). Water stress can affect growth, development, and physiological processes of maize, eventually reducing biomass and grain yield (Payero, Tarkarson, Irmak, Davison & Petersen, 2008). Several studies have suggested that maize yield is proportional to seasonal evapotranspiration (ET) or transpiration (Djaman, Irmak, Rathje, Martin, & Eisenhaur, 2013). This implies that negative ET anomalies are a good predictor of negative yield anomalies (Barrett & Skogerboe, 1978; Gilley, Watts, & Sullivan, 1980; Hanks, 1974; Hanks, Keller, Rasmussen, & Wilson, 1976; Klocke, Schneekloth, Melvin, Clark, & Payero, 2004; Schneekloth, Klocke, Hergert, Martin & Clark, 1991; Stone, 2003). These studies document significant differences in hybrid-specific responses of maize to water stress, suggesting that there is a broad spectrum of hybrids, tested in different climatic environments, which have different yield responses to reduced evapotranspiration. The choice of appropriate hybrids, on the basis of expected seasonal ET, may therefore offer significant opportunities for the adaptation of maize production systems to reduced water availability.

A precise and detailed knowledge of the soil water balance and of crop water use is needed to design effective irrigation schedules. In Mediterranean environments the efficient use of irrigation water has a fundamental importance, since agro-ecosystems are vulnerable to water scarcity under semi-arid climate conditions.