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Climate change and Mediterranean agriculture: Impacts on winter wheat and tomato crop evapotranspiration, irrigation requirements and yield

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ABSTRACT

High resolution climate data, derived from the ENSEMBLES Regional Climate Models outputs, were used to assess the impacts of climate change on crop water and irrigation requirements and yield of winter wheat and tomato in the Mediterranean region. Data, based on the A1B emission scenario, were arranged purposefully to represent the years 2000 and 2050. Over this 50-years span, an overall reduction of annual precipitation of 39.1 ± 55.1 mm and an increase of air temperature of 1.57 ± 0.27 °C (from 0.84 to 2.31 °C) are predicted. The consequent increase of annual reference evapotranspiration is 92.3 ± 42.1 mm (6.7%). The potentially cultivable areas of winter wheat and tomato may increase by 7 and 24%, respectively, and might be extended prevalently in the Northern Mediterranean countries. The average length of growing season was estimated to be shorter in 2050 by 15 and 12 days for wheat and tomato, respectively. Due to anticipation and shortening of growing season, the crop evapotranspiration is foreseen to be reduced by 6 and 5% for wheat and tomato, respectively. The net irrigation requirements (NIR) under optimal water supply may decrease by 11% for wheat and 5% for tomato. Under moderate deficit irrigation, NIR are foreseen to decrease by 14 and 7% respectively for wheat and tomato. As a whole, a slight increase of relative yield losses (RYL) is expected for rainfed wheat, particularly in the Northern Mediterranean. Overall, tomato RYL are not expected to change in the future. The foreseen impact of precipitation decrease is more relevant for winter-spring crops. Hence, the adoption of supplemental irrigation for winter wheat could become more widespread also in the northern Mediterranean countries. Differently, for tomato, cropped in most areas out of the rainy season, the irrigation strategies are expected to remain similar as today.

1. Introduction

The Mediterranean region develops from the arid/semi-arid climate of North Africa and Middle East up to the temperate and humid climate of northern and central Europe. For that reason, even relatively minor modifications of the global climate may lead to important changes in the Mediterranean climate (Giorgi and Lionello, 2008). Most assessment studies analysing long-term series of historical weather data (Kostopoulou and Jones, 2005) and using a range of global and regional climate models have shown that the Mediterranean region is among the “Hot-Spots” in future climate change (CC) projections (Giorgi, 2006). This is due to a significant positive trend of air temperature in the past and an expected larger warming than the global average in the future, and to an expected decrease of precipitation and an increase in its inter-annual variability. The latter is particularly relevant considering that water scarcity is already quite high in several areas.

It is foreseen that CC will negatively affect vegetation water availability due to variation in rainfall amounts, changes in dry spells frequency and intensity, and expected decrease in rainfall infiltration (Pereira, 2011). Impacts on crop yields and water productivity are consequently expected, also due to changes in temperature and increased atmospheric CO_2. Higher CO_2 concentration

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will likely increase plant production due to its fertilizer effects on photosynthesis, mainly for C3 plants (Drake et al., 1997). Lower yields may be expected due to shorter growing seasons, increased heat and water stress and greater water scarcity (Rosenzweig and Tubiello, 1997; Harrison et al., 2000; Olesen and Bindi, 2002; Fischer et al., 2007; Quiroga and Iglesias, 2009). The response of agricultural systems to future CC also depends on adopted management practices, especially the availability and levels of applied water (Tubiello et al., 2000; Pereira and de Melo-Abreu, 2009). Probably, the most affected aspects refer to the changes of phenological dates, length of crop seasons (LCS), crop water requirements (CWR), net irrigation requirements (NIR) and related yield changes.

Crop phenology has been indicated as a key-point for assessing the impact of CC on agricultural crops (Moriondo and Bindi, 2007). Temperature has a direct effect on the geographic distribution of crops; some species will benefit from warmer growing season, while others will disappear or move to higher latitudes or altitudes. In the Mediterranean region, a northbound shift of growing areas for some crops is expected in response to the predicted increase in temperature (Bindi et al., 1996; Tanasijevic et al., 2014). Reference evapotranspiration, ET_o, is expected to increase due to CC, especially in winter and spring when the increase of temperature could be higher (Moratiel et al., 2011; Pereira, 2011). Many studies reported an increase of CWR and NIR in the Mediterranean region (Döll, 2002; Fischer et al., 2007; Rodriguez-Diaz et al., 2007; Giannakopoulos et al., 2009). However, Supit et al. (2010) found a downwards trend for CWR in Europe, and Lovelli et al. (2010) reported an expected decrease of wheat NIR in Southern Italy. Due to CC, crop yields will change depending on the latitude, temperature, water availability and irrigation. On average, across several species and unstressed conditions, the increase of atmospheric CO_2 concentrations to 550 ppm may increase crop yields in the range of 10–20% for C3 species and 0–10% for C4 crops (Ainsworth et al., 2004; Ainsworth and Long, 2005). However, crop productivity is likely to decrease where precipitation decreases significantly such as some Mediterranean areas where yield could decline up to 30% considering the horizon of 2050 (Olesen and Bindi, 2002).

In view of expected population growth and relevant environmental concerns, it is unlikely that agriculture can ensure a larger share of the already highly exploited fresh water resources in the future (Zwart et al., 2010; Milano et al., 2012). For that reason, increasing water productivity (WP) in irrigation is a priority issue (Molden et al., 2010; Pereira et al., 2012) especially in the areas already characterized by water scarcity and high irrigation inputs, as it is the Mediterranean region.

This study takes into consideration the foreseen climatic changes in the Mediterranean area for the period 2000–2050 with the aim to assess and map the impact of CC on the cultivation of winter wheat and tomato in terms of the length of crop cycle, crop evapotranspiration, net irrigation requirements, and relative yield losses under various irrigation scenarios. These crops are of strategic importance for Mediterranean agriculture and permit to analyze two different growing periods, autumn-spring for wheat and spring-summer for tomato. High resolution of input climate data allows the mapping of results to provide the spatial patterns of impacts over the whole region and to identify hot spots where changes could be particularly relevant. However, because the assessment was performed on a very wide scale it was not intended to focus on soils and land use distribution but on climate influences.

2. Materials and methods

2.1. Climate data

Climate data have been derived in the WASSERMed project (EC-FP7-ENV) from the Regional Climate Models (RCMs) outputs that have been produced by the ENSEMBLES project (EC-FP6-ENV). Two sets of RCMs forced by two different Global Circulation Models (GCMs) were taken into consideration: RACMO2, REGCM3, RCA and REMO were forced by ECHAM5 and HIRHAM5, PROMES, CLM and HadRM3Q0 by HadCM3Q0. Data referred to the SRES emission scenario A1B (IPCC, 2000). Model time series were divided into three time slices: (i) past, 1961–1990, (ii) present, 1991–2010, and (iii) future, 2036–2065. The time slice "Past" has been used to "validate" models through the comparison between their outputs and the gridded observational CRU (Climate Research Unit) dataset of the East Anglia University (Mitchell and Jones, 2005). The validation suggested that RCMs driven by ECHAM5 were more accurate than those driven by HadCM3Q0 in the Mediterranean region. Therefore, RCM simulations driven by ECHAM5 were used for producing a multimodel ensemble, which, in general, has shown to provide robust and reliable results for all climate variables and statistics (Christensen and Christensen, 2007; Jacob et al., 2007). All model results have been interpolated on a 0.25° × 0.25° (latitude by longitude) grid. The climatic database extends from South-West (−9° W, 30° N) to North-East (37.3° E, 57° N) and does not cover southern regions of North Africa which mainly represent desert areas not suitable for agricultural production. The same base data were used for a study on CC impacts on olives water requirements and cultivation in the Mediterranean region (Tanasijevic et al., 2014).

The climatic variables, available on a monthly basis, included: precipitation (mm), air temperature (°C) and relative humidity (%) at 2 m height, solar radiation ($W\,m^{-2}$) and wind speed at 10 m ($m\,s^{-1}$) adjusted to 2 m height according to Allen et al. (1998). The climatic input database represented two time periods: (i) present, called year 2000 (average values of simulations for the period 1991–2010), and (ii) future, called year 2050 (average values of simulations for the period 2036–2065). Daily climate data on air temperature, humidity, solar radiation and wind speed were generated from monthly data using a simple linear interpolation method where the average monthly values were assigned to the mid day of each month. Daily precipitation values were distributed randomly over a month using a simplified approach aimed at the very large scale of the study area. Because the number of monthly rainy days was missing, the maximum number of rainy days (N_{max}) was estimated as $N_{max} = \mathrm{Int}(P/n)$, with $n = 10$ when the monthly precipitation was $5 < P < 300$ mm (280 mm in February), $N_{max} = 1$ when $P \leq 5$ mm and $N_{max} = 30$ when $P > 300$ mm. The number of rainy days (N) was determined randomly in the range [$N_{max}/2$, N_{max}] for all months where $N_{max} \geq 2$. A random function was then applied to identify the rainy days in a month assuming a precipitation amount of P/N. This procedure was applied to every grid point.

2.2. Methodology

The methodology adopted in this study was based on the application of Geographical Information Systems (GIS) using the ArcView GIS (version 9.3) software. Soil data on depth, texture and available water content were obtained from the harmonized soil database, HWSD version 1.2 (FAO/IIASA/ISRIC/ISSCAS/JRC, 2012). The soil mapping units were linked to the harmonized attribute data which allows to display and use these data in GIS and to perform a simple soil water balance in correspondence with the weather data. All elaborations were based on the 0.25° × 0.25° grid. Dominant soil type was considered in each grid cell when soil data were integrated with climatic data. However, it was not possible nor intended to check the soil suitability at the same scale. The methodological approaches were the same for both crops and included the following steps which are detailed hereafter:

(i) determination of the starting dates of the growing season;