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Impacts of climate change on olive crop evapotranspiration and irrigation requirements in the Mediterranean region

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ABSTRACT

The Mediterranean basin is the largest world area having specific climatic conditions suitable for olive cultivation, which has a great socio-economic importance in the region. However, the Mediterranean might be particularly affected by climate change, which could have extensive impacts on ecosystems and agricultural production. This work focussed on the climate change impact on olive growing in the Mediterranean region considering the possible alterations of cultivable areas, phenological dates, crop evapotranspiration and irrigation requirements. Monthly climate data, with a spatial resolution of $0.25^\circ \times 0.25^\circ$ (latitude by longitude), have been derived from Regional Climate Models driven by ECHAM5 for the A1B scenario of the Special Report on Emissions Scenarios (SRES). The data used in the analysis represented two time periods: (i) present, called year 2000 (average values for the period 1991–2010), and (ii) future, called year 2050 (average values for the period 2036–2065). The areas suitable for olive cultivation were determined using the temperature requirements approach known as the Agro Ecological Zoning method. Crop evapotranspiration and irrigation requirements were estimated following the standard procedure described in the FAO Irrigation and Drainage Paper 56. Results showed that the potentially cultivable areas for olive growing are expected to extend northward and at higher altitudes and to increase by 25% in 50 years. The olive flowering is likely to be anticipated by 11 ± 3 days and crop evapotranspiration is expected to increase on average by 8% (51 ± 17 mm season^{-1}). Net irrigation requirements are predicted to increase by 18.5% (70 ± 28 mm season^{-1}), up to 140 mm in Southern Spain and some areas of Algeria and Morocco. Differently, effective evapotranspiration of rainfed olives could decrease in most areas due to expected reduction of precipitation and increase of evapotranspirative demand, thus making it not possible to keep rainfed olives' production as it is at present.

1. Introduction

Olives (*Olea europaea* L.) are among the oldest domesticated species and one of the best adapted crops to the marginal sub-humid and semi-arid lands of Mediterranean. Olives are a cash crop of great economic importance and may be considered a strategic crop in the region because highly adaptable to dry spells and drought, and able to attain acceptable yield under dry farming. Nevertheless, recently, the irrigation of olive orchards took increased in importance because traditional olive groves are progressively abandoned giving place to high intensive orchards that produce larger yields and economic returns (Duarte et al., 2008; de Graaff et al., 2010; Freixa et al., 2011).

The Mediterranean region seems to be particularly affected by climate change. The warming is projected to be greater than the global average, with also a large percent reduction of precipitation and an increase in its inter-annual variability (Giorgi, 2006). A pronounced decrease in precipitation over the Mediterranean is expected, except for the northern areas (e.g. the Alps) in winter (Giorgi and Lionello, 2008). The authors explained this drying with the increased anti-cyclonic circulation that yields increasingly stable conditions and with a northward shift of the Atlantic storm track. Giorgi and Lionello (2008) also predicted a pronounced warming, maximum in the summer season, with high inter-annual

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variability and a greater occurrence of heat waves and dry spell events. Hertig and Jacobeit (2008) reported a similar temperature increase, ranging mostly between 2 and 4 °C when the period 2071–2100 is compared to 1990–2019, depending on region and season. Such climate changes, along with rising CO_2 concentration, are expected to have extensive impacts on ecosystems and agricultural production with associated consequences on water availability and distribution, pest and disease occurrence, and overall socio-economic development. Probably, the most affected variables will be the duration of phenological stages, crop evapotranspiration, irrigation requirements and biomass growth and yield (Osborne et al., 2000; Pereira and De Melo-Abreu, 2009; Quiroga and Iglesias, 2009). Further, though the factors that prevail regionally may change over time gradually, a more rapid climate change may occur in some areas.

Crop growth and development strongly depends on local climatic conditions. Each crop has different climatic and environmental requirements for normal growth (e.g., temperature, light, slope orientation, soil fertility, water availability, nutrients). These variables may be affected by climate change, especially temperature, due to its impact on the plant development (Galán et al., 2001). Temperature rise leads, in most areas, to a shift in the optimal growing period, often by a month or more into the winter season, and may sometimes even cause a change in the cropping pattern (Galán et al., 2005; Avolio et al., 2008). Thus, some crops, which currently grow mostly in Southern Europe, will become more suitable for cultivation further north or in higher altitude areas in the south (Audsley et al., 2006; Olesen et al., 2007; Moriondo et al., 2010). A study by Gutierrez et al. (2009) showed that in Italy the areas suitable for olive cultivation are expected to extend and include new zones at higher elevations in central Italy and the Po Valley in the north. Climate warming may also increase the range of olive fly northward. Similar conclusions were reported for the Mediterranean region by Ponti et al. (2013). Global warming is expected to affect the phenology dates of plants, particularly olives (Galán et al., 2005; Bonofiglio et al., 2008; García-Mozo et al., 2010; Oteros et al., 2013). There is an overall trend of earlier occurrence of key phenological events such as flowering and a consequent shortening of the crop growth phases (Osborne et al., 2000; Giannakopoulos et al., 2009; Moriondo et al., 2008, 2010; García-Mozo et al., 2010). This advance of phenological phases is more evident in arboreal than in herbaceous crops (García-Mozo et al., 2010) resulting in a shorter time for biomass accumulation and yield formation (Bindi et al., 1996; Olesen et al., 2011).

Flowering is the critical phase for olive development, hence it may be a sensitive and reliable indicator of inter-annual variability of temperature in the Mediterranean, particularly for spring temperatures (Osborne et al., 2000; Orlandi et al., 2005, 2010). De Melo-Abreu et al. (2004) reported that olives require a certain period of low temperatures (chilling requirements) for normal flowering, hence with a warmer climate olive flowering could advance for almost one month, while much warmer scenarios indicate no normal flowering in some varieties. Oteros et al. (2013) demonstrated that changes in phenological dates not only vary with temperature and water availability but also with altitude and exposition. Model simulations indicated that the flowering date for olives in the western Mediterranean could occur significantly earlier by the end of this century (Osborne et al., 2000). Several studies, using different methodologies, addressed the temperature requirements before the start of flowering of olives in different sites of Spain and Italy (Galán et al., 2001, 2005; Avolio et al., 2008; Bonofiglio et al., 2008). They concluded that with the further temperature rise it could be necessary to introduce new varieties with lesser chilling requirements; otherwise, it would be required to move production into other areas with lower temperature. In fact, due to the changes in temperature and precipitation patterns, the area climatically suitable for olive cultivation could be enlarged northwards and to higher altitudes, thus increasing the range of areas suitable for olives into new areas of France, Italy, the Balkans and the northern Iberian Peninsula (Bindi et al., 1992; Bindi and Howden, 2004; Moriondo et al., 2008; Gutierrez et al., 2009).

Olive is sensitive to longer periods of freezing and, although resistant to water shortage, produces best with high rainfall or with irrigation (Palomo et al., 2002; Moriana et al., 2003; Iniesta et al., 2009; Palese et al., 2010; Martinez-Cob and Faci, 2010). Therefore, the olive cultivation in the future could require more water input than today but water availability is likely to be reduced (García-Ruiz et al., 2011; Milano et al., 2012). The atmospheric water demand, expressed through the reference evapotranspiration (ET_o), is expected to increase directly with temperature rise and due to the changes of net radiation (Pereira, 2011): long wave radiation is predicted to increase with increased greenhouse gases, while shortwave radiation could decrease with increasing of cloudiness. Thus, ET_o is expected to increase due to climate change. A greater percentage of ET_o increase is foreseen for the winter season, but, in absolute value, the increases may be higher in the summer months. Various studies confirmed an increase of ET_o under climate change (Döll, 2002; Rodriguez-Diaz et al., 2007; Moratiel et al., 2011).

As per the review above, there is a good knowledge on olive trees processes that may be affected by climate change. However, there is large uncertainty about the temporal and spatial variation of the above mentioned impacts through the Mediterranean basin. Crop evapotranspiration (ET_c) and net irrigation requirements (NIR) are particularly uncertain, as well as the pattern of changes in the areas suitable for olive cultivation. Thus, studies that permit a spatial elaboration of data and presentation of results at both country and regional scales could be particularly relevant. This could bring additional insight regarding agricultural water management at different scales and promote active management strategies optimizing water use and yield production. Hence, this study aims at understanding the impacts of foreseen climate change on olive cultivation in the Mediterranean countries and region by comparing a baseline climate, defined for year 2000, with a future one assumed for 2050. The study focuses on crop evapotranspiration, irrigation requirements and water stress impacts on rainfed olive cultivation, while considering the expected shifting of the flowering time and future changes in the areas suitable for cultivation.

2. Materials and methods

2.1. Climatic data

This work used climate data that were derived within 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 considered: RACMO2, REGCM3, RCA and REMO were forced by ECHAM5, and HIRHAM5, PROMES, CLM and HadRM3Q0 by HadCM3Q0. Model time series were divided into three time slices: (i) Past: 1961–1990, (ii) Present: 1991–2020, 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 East Anglia University (Mitchell and Jones, 2005). This validation suggested that two RCM datasets have comparable quality, though those driven by ECHAM5 have lower overall bias for precipitation in spring and temperature in summer. Therefore, RCM simulations driven by ECHAM5 have been used for producing a multi-model ensemble, which, in general, has been shown to provide robust and reliable results for all climate