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Future climate change in the Mediterranean area: implications for water use and weed management

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Abstract

Results obtained within research activity from the Climesco Italian Project are summarized. These results suggest that in regards to the impact of climate change in the Mediterranean area, a decrease of water availability and a more frequent occurrence of drought periods are expected. In order to describe the main effects of climate change on water use in some agro-ecosystems in the Mediterranean area we showed that the Penman-Monteith equation can be modified to simulate future changes in reference evapotranspiration by recalibration of the crop resistive parameter. Moreover, the use of adjusted crop coefficients (Kc) can help quantify the climate change impact on water use for irrigated crops grown in Southern Italy and elsewhere in the Mediterannean. For this region temperature rise and the concomitant expected rainfall reduction may lead to an increase yearly potential water deficits. For autumn-spring crops a further increase of water deficit is not expected. In contrast for a significant increase of water deficit, and thus of irrigation needs, is expected for spring-summer crops. Another aspect considered in this review is how in the Mediterranean area, drought conditions and warmer temperatures will alter the competitive balance between crops and some weed species. We report experimental data showing how weed aggressiveness and competition is already increasing due to warmer temperatures in the Mediterranean region.

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Introduction

The IPCC third assessment report (IPCC 2001) emphasized that climate change was likely to be associated with extremes of water availability. Indeed, drought in some area of the world may become so widespread and so severe in the coming decades that current drought indices may no longer work properly in quantifying future drought (Dai, 2010).

However, because of the coarseness of existing models, it is unclear which regions are likely to experience drought in the future. That is, from a hydrological standpoint, not all regions will respond in a similar fashion to recent and projected increases in global mean temperature. From this point of view, one of the most critical regions is the Mediterranean basin, where a non uniform and discontinuous warming was identified and a strong east-west differentiation in temperature trends was well documented (Kostopoulou and Jones, 2005). A number of researchers have, in fact, suggested that significant impacts are likely in southern Europe and the Mediterranean, where warming greater than the average is expected, mostly in summer, with a subsequent increase in heat waves and a significant rainfall decrease (IPCC, 2007; Olesen and Bindi, 2002, Vitale *et al.*, 2010).

Because agriculture is recognized globally as a principle user of water for irrigation; agriculture in the Mediterranean region will be affected by climatic change both directly (changes in precipitation and water sources, changes in the evapotranspiration rate), and indirectly (greater competition with weeds) (Vergni and Todisco, 2010). Implementation of agronomic techniques regarding cultivation, water use, nutrient and weed management could reduce the impact of increasing drought frequency in the Mediterranean region. In this context it is of paramount importance to simulate the future changes of crop evapotranspiration and future irrigation requirement of crops usually cultivated in the Mediterranean area. In addition, it will be necessary to understand the impact of temperature and droughts on Mediterranean agro-ecosystems in general and on weed management, in particular.

Temperature and drought impacts on potential water use of crops in the Mediterranean

Crop water requirement is function of several climatic parameters, including rainfall, radiation, temperature, humidity and wind speed. Thus, variation in climatic parameters are also likely to affect evapotranspiration (Goyal, 2004). However biological factors such as plant growth, canopy structure and stomatal responses to the environment (Moratiel *et al.*, 2010) will also influence water use.

At the individual plant level, CO_2 induced changes in stomatal conductance, could result in reduction in water use, and an increase in carbon assimilation, with an overall increase in water use efficiency. However, at the canopy level, a decrease in transpiration also results in a lower thermoregulatory effect and consequently an increase in temperature. It is unclear if, in turn, the increase in canopy temperature is sufficient to negate any stomatal induced changes in transpiration (Bernacchi *et al.*, 2007). At the whole canopy level, the latter effects could potentially nullify the reduction of stomatal conductance observed in single leaves (Polley, 2002; Bernacchi *et al.*, 2007). On these latter aspects regarding canopy water use and efficiency there is still uncertainty (Bernacchi *et al.*, 2007).

Actually, at the canopy level, both abiotic and biotic variables intervene, including surface layer and mixed layer feedback as well as stomatal conductance and canopy microclimate (Wilson *et al.*, 1999). These variables, in turn, are related to leaf area, canopy temperature, irradiance, wind speed, vapour pressure deficit (VPD), and canopy architecture (McNaughton, 1983; Baldocchi, 1994; Morecroft and Roberts, 1999). Overall, with respect to feedbacks and enhanced leaf area anticipated with rising carbon dioxide, the simulated decrease in ET at the canopy level is likely to be significantly less than the decrease in conductance observed for single leaves (Wilson *et al.*, 1999; Bernacchi *et al.*, 2007)

Although assessments of CO_2, climate change and water use have been conducted elsewhere, principally North America (*e.g.* Kimball, 2004), there are not similar data for the Mediterranean region. Considering the complexities of CO_2, climate and evapotranspiration we estimated changes in reference evapotranspiration (ETo) in the Mediterranean area as a consequence of climate change using the standardized Penman-Monteith (PM) equation (Allen *et al.*, 1998; 2006). Our approach differed from other assessments (*e.g.*, Rosenberg *et al.*, 1990; Moratiel *et al.*, 2010), in our consideration of canopy conductance (Lovelli *et al.*, 2010b).

Taking into account published values regarding atmospheric CO_2 on stomatal conductance (Ainsworth and Long, 2006) (gs), we considered the effect on stomatal and canopy conductance (Lovelli *et al.*, 2010b). We also considered the temperature increment effect on the reference evapotranspiration (ETo) variation, comparing the evapotranspiration assessment obtained using the PM equation with that obtained by modifying the canopy resistance parameter (Lovelli *et al.*, 2010b). These data suggest that any reduction in stomatal conductance is able to control the effect of climate change only for a narrow set of temperatures (0-2°C; Figure 1). For each value of the daily mean air temperature, Figure 1 indicates that plant adjustment, partially closing stomata, reduces water use. This adaptative plant response to higher levels of atmospheric CO_2 concentration may be negated by an increase in air temperature and seubsequent increase in evapotranspiration rate. This rise would be likely to occur in an environment with a hot-arid climate such as the Mediterranean. This approach may be particularly effective in evaluating climate change driven effects on crop water use because it incorporates climate change effects through the Penman-Monteith equation, recalibrated with respect to canopy conductance.

In simulating the measured historical data (1961-2006 for Southern Italy), our analysis showed that from 1985 on, the annual average temperature followed an increasing trend and, moreover, the rainfall regime changed compared to the measured trend of the previous years. Taking the 1985 as a reference year, the annual mean temperature has risen by 1.3°C in 2006 and a further increment of 4.8°C should be expected in 2071 according to the data from the A2 simulation (Emissions Scenarios A2, Nakicenovic *et al.*, 2000). Despite signficant annual variability, a statistical analysis of rainfall indicated a tendency for a slight decrease.

Recent analysis have suggested that temperature is more likely to change consistently for a given region than precipitation (Lobell *et al.*, 2011). Given that expectations regarding future rainfall trends are still greatly uncertain (Döll, 2002) this will affect forecasts about crop water use in future climate scenarios since such forecasts strongly depend on rainfall timing and amounts.

Impact of climate change on crop coefficients

Some regional climate scenarios show anticipation of drier summers over continental Europe (Giorgi *et al.*, 2001; Rowell and Jones, 2006). Consequently drier weather could lead to more water stress and higher demand for water resources by crops (Fink *et al.*, 2004). Given the potential scarcity of water, proper irrigation scheduling to maximize production while minimizing water use becomes critical. One strategy to achieve this is to improve estimates of crop evapotranspiration. This can be accomplished by deriving the reference evapotranspiration (ETo) through the Penman-Monteith equation and multiplying the obtained value by the crop coefficient (ETc=ETo×Kc) (Allen *et al.*, 1998). However, crop coefficients, also vary as a function of climate (Allen *et al.*, 1998), consequently determination of a more accurate crop coefficient – one that reflects climatic inputs could improve irrigation efficiency. However, at present, there are few studies concerning the impact of increasing temperature on crop coefficients.

Clearly, temperature has a direct effect on the geographic distribu-

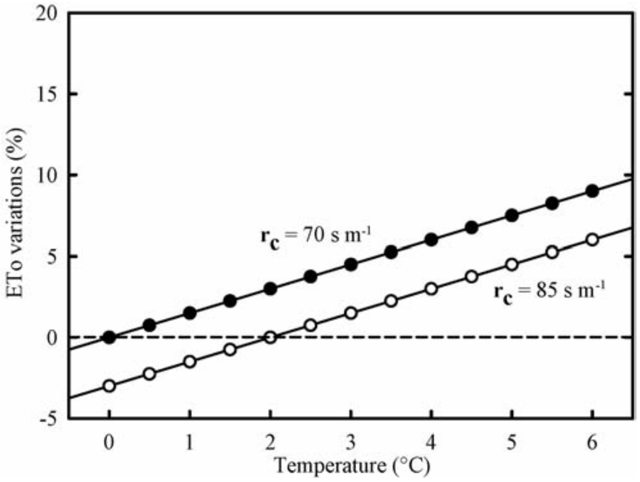

Figure 1. Percentage variations of reference evapotranspiration (ETo) as a function of projected temperature increases, calculated by the Penman-Monteith equation (full circles) and with a recalibration of the canopy resistance parameter (rc), (empty circles), (from Lovelli *et al.*, 2010b).

tion of crops. A northbound shift of some crop growing areas is expected in response to predicted increases in temperature in Mediterranean regions (Bindi, 1992; 1996; 2000). Moreover crop production cycles may shorten, since temperature increases the thresholds for the beginning of the growing season and accelerates harvests (Porter, 2005; Moratiel *et al.*, 2010). More specifically, in seed crops with determined flowering, the achievement of ripening time is closely linked to temperature and day length. Thus, a thermal increase will lead to a shortening of the growing cycle, because increasing temperature results in an accleration of the reproductive phase and shortening of the crop life cycle (Peiris *et al.*, 1996). Because global warming is expected to have an impact on crop phenology any modification may have a significant effect on crop coefficients not accounted for in most estimates of ET.

We considered the climate change impact on water use of major crops grown in the Mediterranean area (wheat, tomato, broccoli and muskmelon). The impact of climate changes on phenological phase length was assessed by the Growing Degree Days (GDD simulation). In the future scenario for the crop evapotranspiration (ETc) assessment, we considered the CO_2 effect recalibrating the canopy resistance (r_s) parameter and the temperature effect by adjusting crop coefficients for meteorological inputs and phenological phase duration. In our simulation we showed that a further adjustment of Kc that takes into account global warming impacts on crop phase length, is necessary to achieve a more accurate estimate of water use. By adjusting Kc according to the

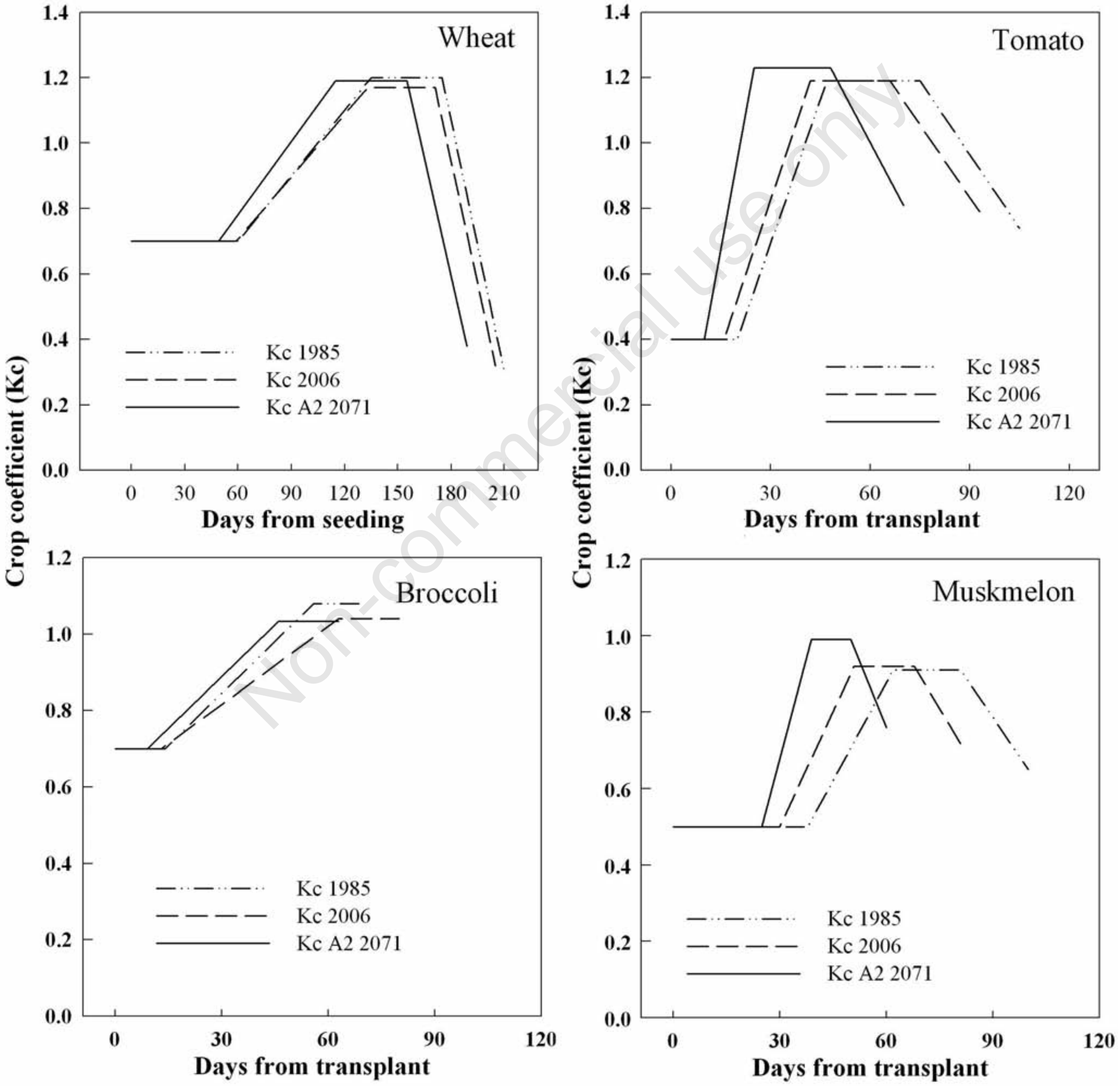

Figure 2. Daily pattern of crop coefficients (Kc) for wheat, tomato, broccoli and muskmelon in 1985, 2006 and for the IPCC A2 scenario for 2071, (modified from Lovelli *et al.*, 2010b).

recent and projected changes in climate using the IPCC A2 scenario, we assessed irrigation requirements of wheat, broccoli, tomato and muskmelon (Figure 2). In general, our results are in accordance with Döll (2002) who states that simulations of irrigation requirements under climate change scenarios, may lead to a shift in the optimal growing period, often by a month or more into the winter season with potential changes in the cropping pattern. As regard to autumn-spring crops such as wheat and broccoli, a further increase in water deficits is not expected. The decrease of water use (due to the reduction of crop cycle length and, to some extent, to the stomatal closure), in the case of the most favourable rainfall distribution, will likely compensate the higher environmental evapotranspirative demand caused by temperature increase in this instance. However, for the spring-summer crops, (*e.g.*, tomato and muskmelon), a significant increase of water deficits, and subsequent irrigation, is expected.

Climate change and water competition between weeds and crops

Weeds impose limitations on crop productivity by competing for resources. One such resource is, of course, water. How weeds will respond to climate change, particularly in regards to water use, is another essential factor in determining irrigation needs and efficiency.

Rising atmospheric CO_2 and climate change are likely to have a significant impact on geographical distribution of weeds and on the severity of weed infestation (Cobb and Reade, 2010). The endemic ability of weeds to adjust phenotypes quickly to environmental change may provide a significant competitive advantage in agro-ecosystems (Cobb and Reade, 2010). How weeds respond to climatic change may, in turn, have significant implications for chemical control of weeds in agriculture (Ziska, 2010). For example rising CO_2 has been shown to reduce the efficacy of glyphosate for Canadian thistle (Cirsium arvense) control (Ziska *et al.*, 2004). Temperature and CO_2 may also favour weed ruderality in terms of seed quantity and seed set (Benvenuti, 2009). In addition, the evolutionary rate in the development of herbicide resistance has been demonstrated to be affect by temperature and soil water availability (Cobb and Reade, 2010).

From the point of view of crop weed competition, climate may bring about two contrasting responses. On one hand, weeds and crops may differ in photosynthetic pathway. This may be significant because the C3 pathway is anticipated to show a stronger growth and photosynthetic response than the C4 pathway due to the CO_2 concentrating mechanism of the latter. In contrast, warmer temperatures could favour the C4 photosynthetic pathway. Since there are a number of C4 crops (corn, sorghum millet) and weeds (pigweed, nutsedge), the effect of CO_2 and/or climate on crop losses due to weeds is difficult to predict. As we showed for pigweed in the Mediterranean environment, photosynthesis is not completely saturated for CO_2. In fact, as Figure 3 clearly shows, in pigweed, a common weed in Mediterranean regions, the operating Ci of photosynthesis under ambient CO_2 concentration is below the inflexion point of the A/Ci curve. This is an important result that could affect competition and increase weed aggressiveness towards crops in the Mediterranean agro-ecosystems (Lovelli *et al.*, 2010c).

If, as seems likely, that CO_2 and/or climatic change will alter the demographics, biology and management of agronomic weeds, water competition is also likely to increase. For example, with respect to water competition our data showed that C4 weeds, such as pigweed, are more drought resistant than pepper and bindweed, C3 weeds (Figure 4). Hence for a given amount of soil water, C4 weeds could develop a larger canopy, grow more root mass and produce more seeds than their C3 competitors (Ludlow, 1985; Long, 1999; Grise, 1996). The relative impact of this, in turn, on water loss, water requirements, and potential changes in crop coefficients has not been sufficiently addressed.

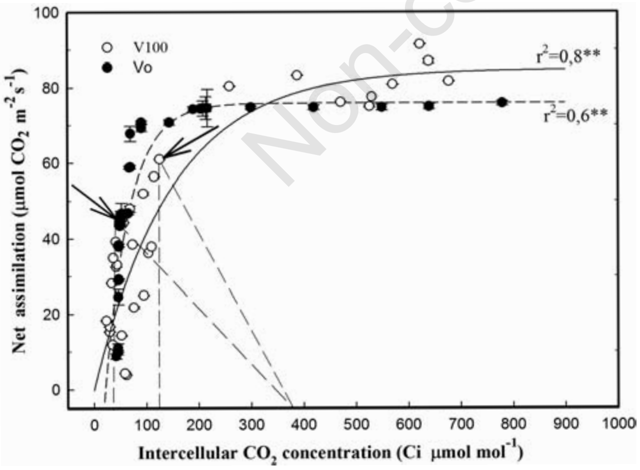

Figure 3. Response of leaf photosynthesis (measured as leaf CO_2 assimilation rate, A) to a range of internal CO_2 concentration (Ci) for single leaves of *Amaranthus retroflexus* L. With irrigation (V100, open symbols, n=4) and not irrigated (V0, closed symbols, n=4). Solid line and dashed lines for the irrigated and not irrigated treatments, respectively. The arrows in the figure indicate the CO_2 assimilation rate at the atmospheric CO_2 concentration (from Lovelli *et al.*, 2010c).

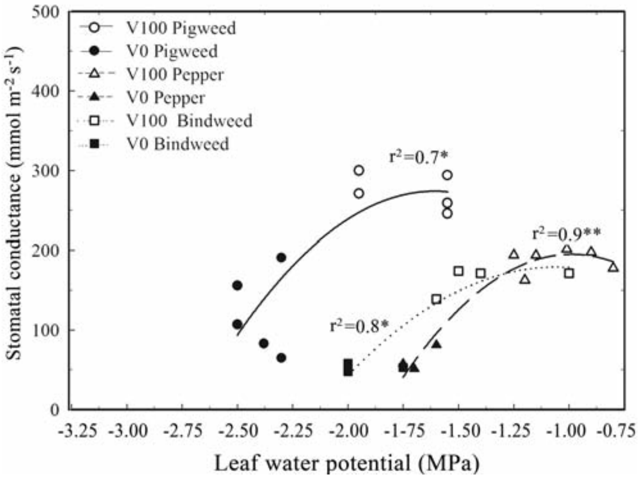

Figure 4. Stomatal water vapour conductance as a function of leaf water potential measured on pepper, pigweed and field bindweed leaves for the irrigated treatment (V100, open symbols, all data measured) and not irrigated treatment (V0, closed symbols, all data measured). Data were fit using non linear regression analysis. Lines are polynomial fit for all data points (from Lovelli *et al.*, 2010a).

Conclusions

As climate becomes more uncertain, and the incidence of extreme events increases, water will become a key factor in maintaining agricultural productivity in the Mediterranean. In this region the temperature rise and the concomitant expected rainfall reduction may lead to an increase in yearly water deficit. For autumn-spring crops a further increase of water deficit is not expected. In contrast, for spring-summer crops a significant increase of water deficit, and thus of irrigation demand, is anticipated. In our climate simulations for crops growing in the spring-summer period the increase in evapotranspirative demand is not compensated by stomatal closure. In addition, our field trials suggest that weed competition may already be increasing due to a warmer climate in the Mediterranean region. The implications of this on crop water use and crop coefficients are unclear.

We would emphasize that there have been few field studies of how temperature, drought and rising CO_2 interact in affecting water use and irrigation demand of major agronomic crops (Long and Ort, 2010). There are GCM predictions regarding production and water availability, but in situ adaptive strategies have not always been elucidated. Given the importance of the Mediterannean region to the food security interests of Europe and Africa, and the importance of water in this region, that there is a critical need for additional research in this area as a means to limit future climate change impacts.

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