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IMPACT OF CLIMATE CHANGE ON CROP EVAPOTRANSPIRATION AND IRRIGATION REQUIREMENTS IN THE MEDITERRANEAN WITH A SPECIAL FOCUS ON THE COUNTRIES OF FORMER YUGOSLAVIA

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Abstract

High resolution climate database developed within the WASSERMed (EU-FP7-ENV) project, are used to estimate the expected changes in agricultural water requirements in the countries of former Yugoslavia. The climate data, based on A1B SRES scenario, referred to the actual situation (year 2000) and the future climate (year 2050). The results indicated that the air temperature increase could go from 1.3°C in Slovenia to 1.7°C in FYROM, while the precipitation is expected to decrease from 30-40 mm year^{-1} in Bosnia and Herzegovina and Serbia to about 80 mm year^{-1} in Montenegro and FYROM. The precipitation could remain unchained in Croatia, while in Slovenia a slight increase of 10 mm year^{-1} is expected. Evapotranspirative demand is foreseen to increase from 35 mm year^{-1} in Slovenia to 84 mm year^{-1} in FYROM.

By the mid of this century, the increase of air temperature could contribute to the anticipation and shortening of crop growing cycle for most crops. Hence, crop evapotranspiration and irrigation requirements could decrease especially for the winter-spring crops. However, the perennial crops water requirements could remain the same or even increase due to reduction of precipitation. Overall water requirements of agricultural sector could be slightly lower or remain almost the same as today because the shortening of the growing cycle could counterbalance the increase of evaporative demand and decrease of precipitation in the region. In any case, the impact of climate change could be distributed in a dissimilar way throughout the region due to spatial and temporal variation of future precipitation pattern and air temperature trend.

Keywords: *Air temperature, precipitation, water balance, evapotranspiration; irrigation; A1B SRES scenario.*

Introduction

Climate change studies have been getting major scientific interest in the last decades. This is due to numerous facts confirming the negative climate change trend which affects the functioning of bio-physical system and almost all sectors of economy (IPCC, 2014). This has recognized recently also on the World Climate Summit, convened at the UN Headquarters in New York (USA) on 23rd September 2014. The Summit brought together more than 100 Heads of State, ministers and leaders from international organizations, business, finance, civil society and local communities, who strengthened a treaty to mobilize the political support and momentum necessary to reach urgently a global agreement on climate change and galvanize action on the ground across all sectors.

Impacts of climate change on agricultural sector could be particularly relevant especially when linked to a number of factors such as population growth, socio-political issues, inadequate agricultural infrastructures, land degradation, heavy disease burden, poor soils and unfavourable climate (Todorovic et al., 2014). Numerous studies reported that the rising of air temperatures, changing of precipitation regimes, and increased atmospheric carbon dioxide levels will largely affected agricultural production (Linderholm, 2006; Fisher et al., 2007; Pereira and de Melo-Abreu, 2009; Lovelli et al., 2010). Biophysical effects of climate change on agricultural production could be positive in some agricultural systems and regions, and negative in others, and these effects will likely vary in seasons and time. For that reason, one of main challenges is to guarantee satisfactory food supply in the future knowing that within the 50-year span (2000-2050) world population would increase by 42%, food demand by 60% (30% of that due to changes in diets) (FAO, 2011), and that water for agricultural sector could be likely reduced by 18% (Strzepek and Boehlert, 2010). Hence, the studies investigating the impact of climate change on agricultural production and water requirements are of great importance to identify the capacity of agricultural systems to act and react to the changes in progress.

Recent studies pointed out that the Mediterranean region is potentially very vulnerable to climatic changes: large climate shifts were observed in the past (Luterbacher et al., 2006) while the climate projection studies have identified the region as one of the top “Hot-Spots” (Giorgi, 2006; IPCC, 2007). In fact, according to the A1B scenario of the Special Report on Emissions Scenarios (SRES), for the period of 100 years (from the end of 20th to the end of 21st Century), the following changes of climate are foreseen for the Mediterranean region (IPCC, 2007; Giorgi and Lionello, 2008; Hertig and Jacobeit, 2008): i) increase of CO_2 concentration in the atmosphere in a range from 45 to 90%; ii) annual mean warming from 2.2°C to 5.1°C, with the largest warming in summer months; iii) decrease of annual mean precipitation from 4 to 27%, with the largest decrease occurring in summer period; iv) decrease of annual number of precipitation days and increase of frequency of high intensity rainfalls. Accordingly, the increase of frequency and intensity of drought events and heat waves could be expected along with the increasing evapotranspirative demand and reduced precipitation. Hence, it is foreseen that the agricultural production in the future could rely strongly on irrigation. It will create an increasing competition for water resources between agricultural, domestic, industrial and tourism sectors especially in the areas characterized by scarce water availability.

The impact of climate change on the Mediterranean agricultural systems have been studied in the last years, among others, within the frame of WasserMed project (EC-FP7-ENV) funded by the European Commission. The studies focussed on both the regional (Mediterranean) scale and selected case-study areas and pointed out that the effects of climate change on agricultural production will be positive in some agricultural systems and regions, and negative in others (Saadi et al., 2014; Tanasijevic et al., 2014). However, no particular reference has been done on the impact of climate change in the Balkan Peninsula and countries of former Yugoslavia. Accordingly, this work focussed on the area of former Yugoslavian republics since it could be particularly vulnerable to climate change. This is mainly due to the fact that Balkan Peninsula represents a transient zone between the temperate continental climate in the North-Western parts and semi-arid Mediterranean climate, along the coast and in the South. Climate change was considered mainly through the changes of air temperature and precipitation with the objective to estimate the impact on crop water requirements and irrigation over the 50-year period (2000-2050). The analysis has been done for the whole Mediterranean region while the results focused on a comparison of the foreseen regional impact with it expected in the countries of former Yugoslavia.

Materials and methods

The climate data set was derived from from the ENSEMBLES project data (EC-FP6-ENV) and consecutive elaborations within the Wassermed project. RACMO2 Regional Circulation Model (RCM), driven by ECHAM5 Global Circulation Model (GCM) was selected as the most suitable model for this analysis. Data used in the analysis referred to the A1B SRES emission scenario which is one of the most likely to occur (IPCC, 2007). Data included the monthly values of precipitation, air temperature, air relative humidity, solar radiation and wind speed over the whole Mediterranean and former Yugoslavian republics. Data were arranged to represent year 2000 (given through the average of the period 1991-2010) and year 2050 (the average of data generated for the period 2035-2065).

The methodology adopted for data elaboration (Fig. 1) was based on the use of Geographical Information System (GIS). High resolution of input climate data (0.25° x 0.25° latitude by longitude) allowed 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.

It was assumed that the changes of air temperature will modify the starting date of growing season and will determine the extension of the areas suitable for cultivation. The thermal time concept was used to predict the crop development as a function of temperature (Monteith, 1977). The summation of temperatures above a threshold, called base temperature, was considered to simulate crop development and growing season length. Then, the crop evapotranspiration and irrigation requirements were estimated for the years 2000 and 2050 through a simplified water balance considering the changes in precipitation regimes and the variations of evapotranspirative demand of the atmosphere over the 50-year distance.

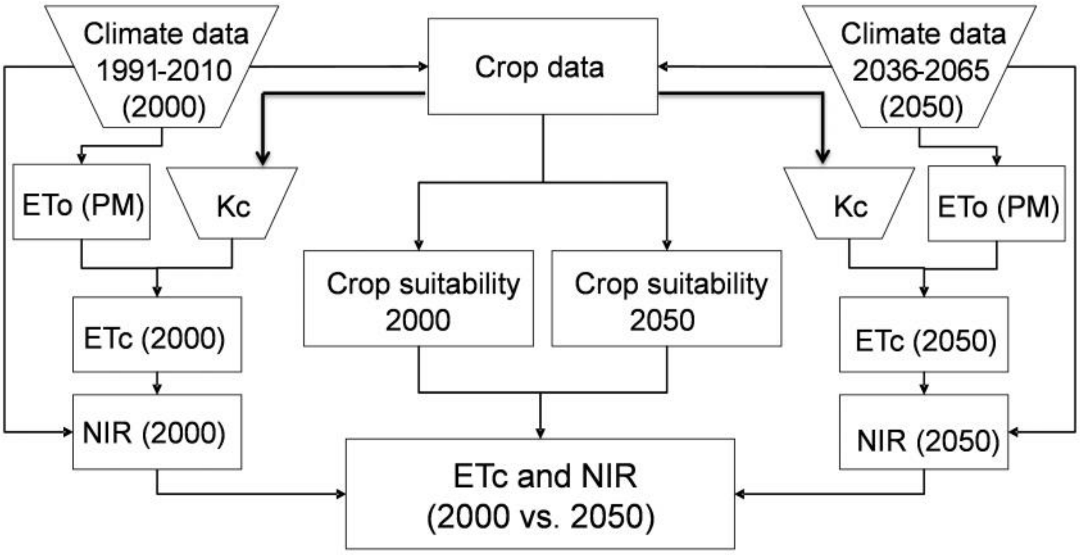

Fig. 1. A simplified scheme of the methodology used for estimation of crop evapotranspiration (ETc) and net irrigation requirements (NIR)

Reference evapotranspiration (ETo) was estimated from full weather data sets using the FAO Penman-Monteith equation (Allen et al., 1998) as:

$$ET_o = \frac{0.408 \cdot \Delta \cdot (Rn - G) + \gamma \cdot \frac{900}{T + 273} \cdot U_2 \cdot (e_s - e_a)}{\Delta + \gamma \cdot (1 + 0.34 \cdot U_2)} \qquad (1)$$

where R_n is the net radiation available at the canopy surface (MJ m^{-2} d^{-1}), G is the soil heat flux density (MJ m^{-2} d^{-1}), T is mean air temperature at 2 m height (°C), U_2 is wind speed at 2 m height (m s^{-1}), (e_a–e_s) is vapour pressure deficit at 2 m height (kPa), Δ is the slope of the vapour pressure curve (kPa $^{o}C^{-1}$) and γ is the psychometric constant (kPa $°C^{-1}$). All parameters were estimated following the standard FAO procedure described in Allen et al. (1998).

Crop evapotranspiration (ET_c), corresponding to crop water requirements, was estimated using the single crop coefficient K_c approach as:

$$\mathrm{ET_c} = K_c ET_o \qquad (2)$$

The K_c values were taken from the literature for the Mediterranean growing conditions (Allen et al., 1998; Pastor and Orgaz, 1994; Er-Raki et al., 2008) and the net irrigation requirements (NIR) were computed as:

$$\mathrm{NIR} = K_c ET_o - P_{eff} = ET_c - P_{eff} \qquad (3)$$

P_{eff} is the effective rainfall assumed to be 80% of total monthly precipitation.

The analysis has been done for a typical winter-spring crop (winter wheat), a typical spring-summer crops (tomato, sunflower and maize), and olive trees which growing season covers the whole year. A more detailed explanation of methodology in given in Saadi et al. (2014) and Tanasijevic et al. (2014).

Results and Discussion

The results of elaboration of climatic data indicated that the air temperature will increase over the whole study area in a range from 1.35°C in Slovenia to 1.67°C in FYROM, therefore, being lower in the North-West areas and increasing gradually towards South-East (Fig. 2). In general, the temperature increase is in the middle of range observed for the whole Mediterranean (from 0.84 to 2.31°C) by Saadi et al. (2014). On the seasonal basis, the temperature increase could be greater in winter (above 1.5° for all regions) and in summer months. Particularly hot summer season could be expected in Serbia (+1.89°C) and FYROM (+2.1°C) increasing the risk of heat stress.

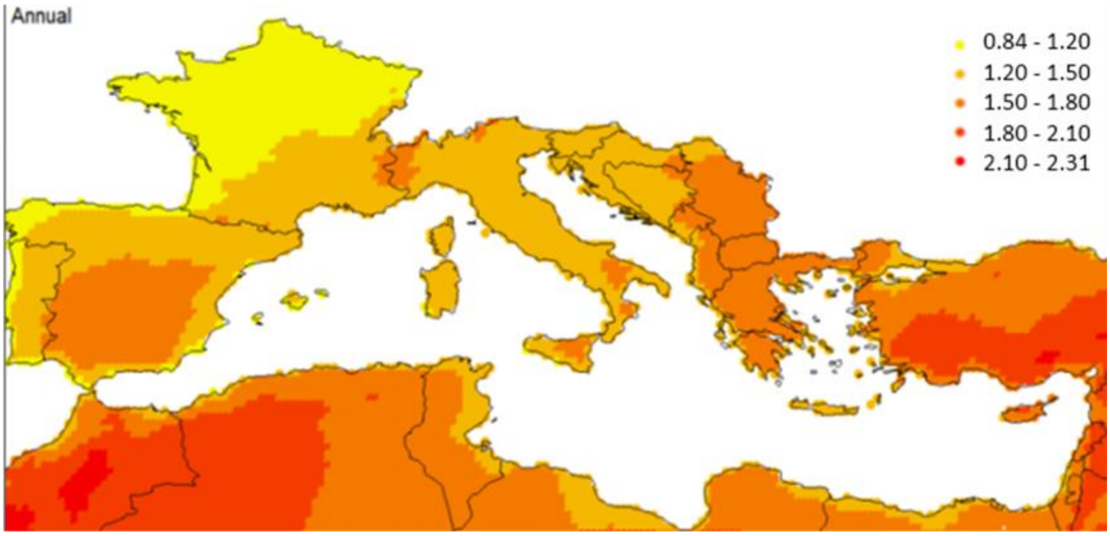

Fig. 2. Expected variation (increase) of average annual air temperature (in °C) over the Mediterranean for the period 2000-2050 (adapted from Saadi et al., 2014)

The precipitation trend could be twofold and depends on the geographic location (Fig. 3). Hence, precipitation is expected to decrease from 30.4±18.9 mm $year^{-1}$ in Bosnia and Herzegovina and 38.5±22.2 mm $year^{-1}$ in Serbia to about 77.1±35.7 mm $year^{-1}$ in Montenegro and 82.4±26 mm $year^{-1}$ in FYROM. On the contrary, the precipitation could remain at the same levels as today in Croatia (-0.6±16.9 mm $year^{-1}$), while in Slovenia an average increase of 9.6±17.5 mm year^{-1} is predicted. In general, the increase of precipitation is foreseen for the North-western parts of Slovenia and coastal areas of Croatia. A particular decrease of precipitation (more than 100 mm year^{-1}) could be expected in some areas of Montenegro and Macedonia (Fig. 3). These areas, together with the western parts of Greece and Iberian Peninsula and northern Morocco, could have the greatest reduction of precipitation in the region.

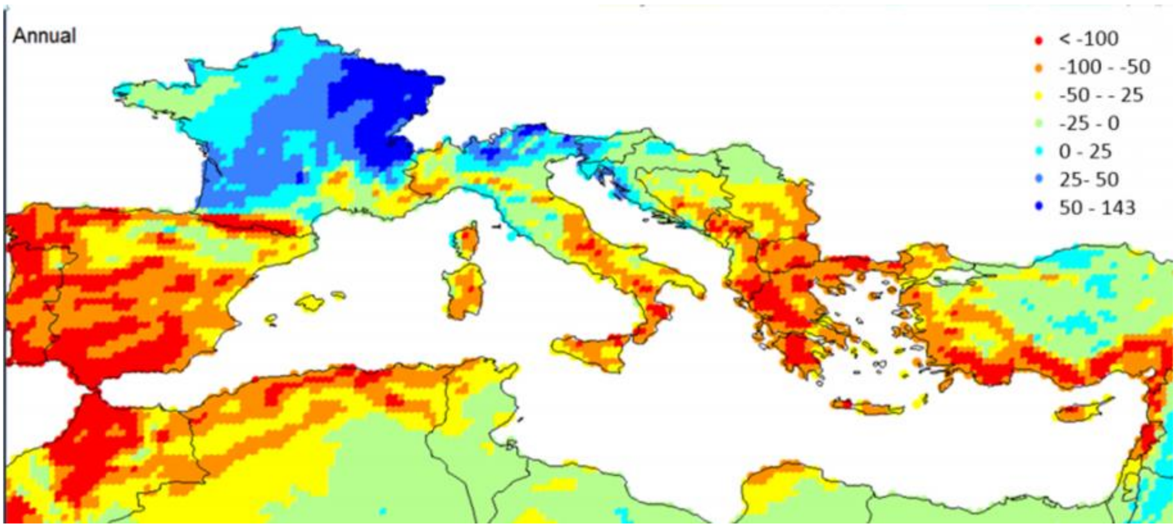

Fig. 3. Expected variation of annual precipitation (in mm year^{-1}) over the Mediterranean for the period 2000-2050 (adapted from Saadi et al., 2014)

Evapotranspirative demand of the atmosphere, expressed through the reference evapotranspiration term, is foreseen to increase over the whole region from 35±3.5 mm year^{-1} in Slovenia to 84±7.7 mm/year in FYROM (Fig. 4). The expected increase of reference evapotranspiration in Croatia, Bosnia and Herzegovina, Montenegro and Serbia is 48.6±7.4, 54.4±4.9, 59.6±2 and 65.7±7.9 mm year^{-1}, respectively. The foreseen change of reference evapotranspiration over the Balkan Peninsula could be similar to France and most of Apennine Peninsula and lower than the average increase over the whole Mediterranean (92.3±42.1 mm year^{-1}). Furthermore, the peak values are much lower than the similar data in some areas Spain, Morocco, Greece and Turkey. In fact, reference evapotranspiration does not follow only the trend of temperature increase (Fig. 2) which means that the expected changes of other climate variables (wind speed, relative humidity and solar radiation) could be relevant and different than that of air temperature in some areas under study.

Olive trees are actually growing only along the Adriatic coast in Slovenia, Croatia, Bosnia and Herzegovina and Montenegro. Due to expected temperature increase, especially during the winter months, the areas suitable for olive trees cultivation could be extended over the continental part of Balkan Peninsula and included many new areas. This is particularly true for Serbia where, by 2050, almost 50% of territory could have a limited suitability for olives growing. Most of these areas are located in the Northern part of country (Vojvodina). Similar situation could occur also in the Northern part of Croatia (Eastern Slavonia) and in the Southern part of FYROM (Tanasijevic et al., 2014). These results, emphasizing the extension of the areas suitable for olive growing, are in agreement with the other studies (Bindi et al., 1992; Gutierrez et al., 2009; Ponti et al., 2013).

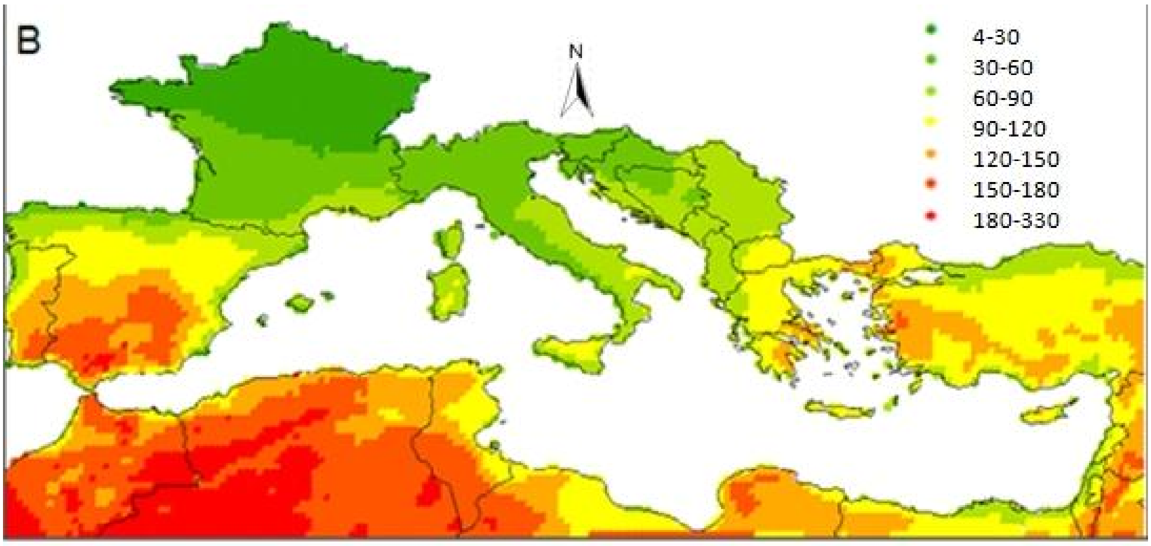

Fig. 4. Expected variation (increase) of evaporative demand of the atmosphere (in mm year^{-1}) over the Mediterranean for the period 2000-2050 (adapted from Saadi et al., 2014)

Olives flowering dates could be likely anticipated in the future, in average over the whole Mediterranean by 11 days. The anticipation of olive flowering in the areas of former Yugoslavia, where the olives are actually grown, could be between 10 and 12 days. This could have a minimum impact on the crop water requirements of olive trees but could affect the harvesting time and yield.

Olive trees ETc and irrigation requirements are expected to increase almost everywhere in the Mediterranean region. The first is due to ETo increase while the second is due to negative water balance and increased water deficit estimated by Eq. 3. Considering the whole Mediterranean region and only the areas where olive trees are actually growing, crop evapotranspiration is expected to increase in average by 8% (51±17 mm season^{-1}) whereas the net irrigation requirements may increase in average by 18.5% (70±28 mm season^{-1}) (Tanasijevic et al., 2014). The expected increase of olive crop evapotranspiration in the Balkan countries is much lower and it is in the range between 20 mm season^{-1} in Slovenia and 31 mm season^{-1} in Bosnia and Herzegovina. Similarly, NIR could increase from 18 mm season^{-1} in Slovenia to 29 mm season^{-1} in Bosnia and Herzegovina which is much less than expected increase over the whole Mediterranean.

In the case of winter wheat, crop water requirements could remain the same as they are today in Montenegro and they could decrease in other countries, from 8%, in FYROM and Slovenia, to 10% (43 mm season^{-1}) in Serbia and 13% (53 mm season^{-1}) in Croatia. This reduction of ETc is greater than the average reduction foreseen for the whole Mediterranean (8% or 33 mm season^{-1}). In general and for the whole Mediterranean, it is worthwhile to point out that the foreseen reduction of winter wheat evapotranspiration was in agreement with other studies (Supit et al., 2010; Ventrella et al., 2012). Irrigation requirements of winter wheat could decrease by 2% in Montenegro and from 14%, in FYROM, to 33% in Croatia. Similarly to the ETc, the reduction of NIR in the future could be greater in the Balkan countries than over the rest of Mediterranean region (an average reduction of 12% is expected).

Maize crop evapotranspiration could be reduced from 1% in Montenegro to 5% in Slovenia (Fig. 5) whereas net irrigation requirements could diminish from 2%, in FYROM and Serbia, to 6% in Slovenia. These variations are in the range of those predicted for the whole Mediterranean (average reduction of 4% could be expected for both ETc and irrigation requirements).

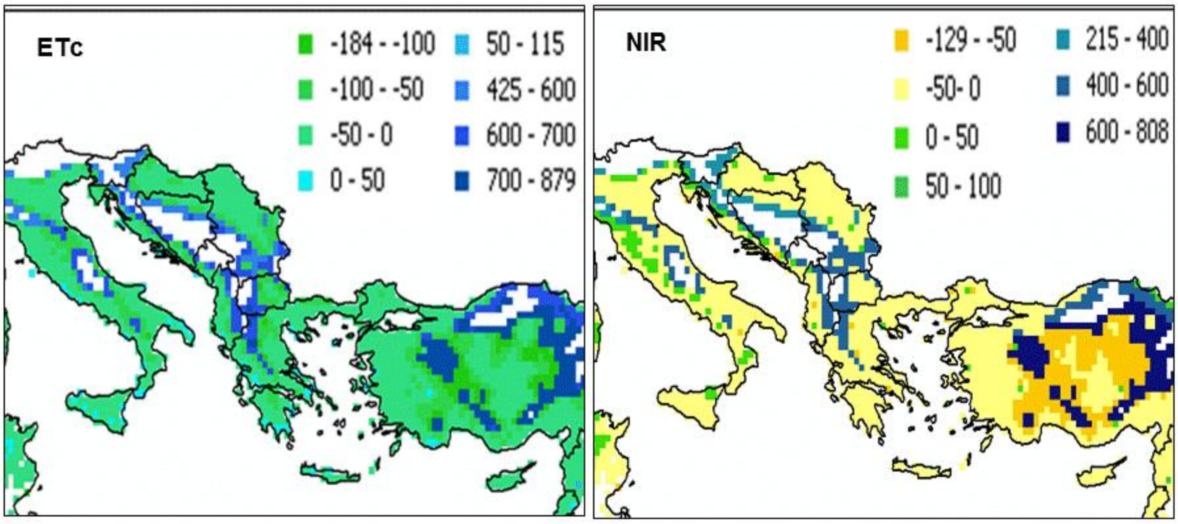

Fig. 5. Expected variation of maize crop evapotranspiration (ETc) and net irrigation requirements (NIR) over the countries of former Yugoslavia and one part of the Mediterranean region for the period 2000-2050 (the reduction of ETc is expected in all areas actually suitable for cultivation while the positive values - blue coloured areas – indicate the zones which could be suitable for the cultivation in the future)

The results of elaborations for sunflower indicated that crop evapotranspiration could likely decrease from 1% in Montenegro to 5% in FYROM and Serbia (Fig. 6). These changes are always lower than expected average crop evapotranspiration reduction over the Mediterranean (5%). In 2050, NIR of sunflower could: a) remain at the actual level in Bosnia and Herzegovina and Montenegro, b) decrease by 1, 2 and 8% in Croatia, FYROM and Slovenia, respectively, and c) increase by 3% in Serbia. This can be explained by the expected variation of precipitation during the spring-summer season which could penalize some areas in respect to the others.

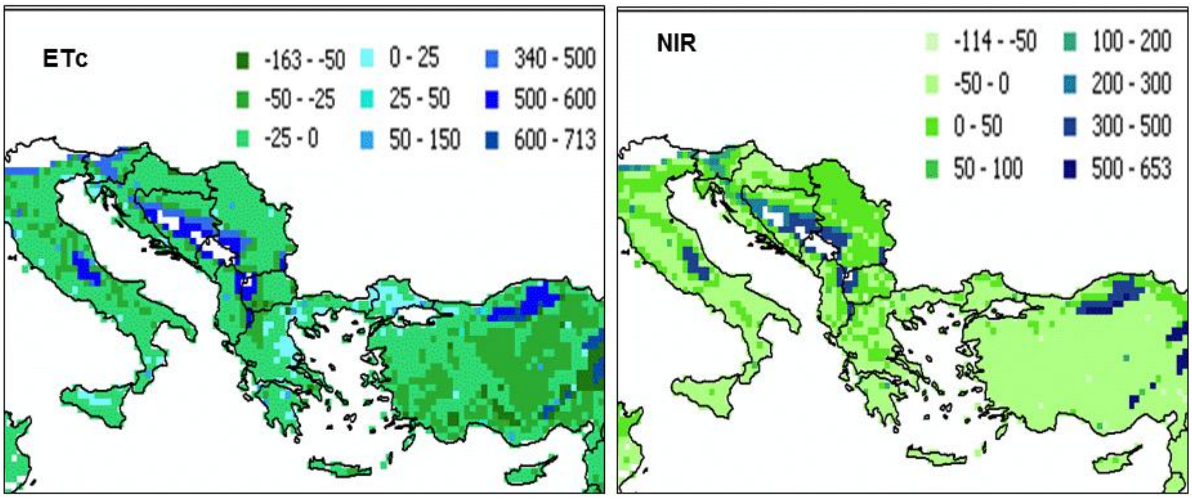

Fig. 6. Expected variation of sunflower crop evapotranspiration (ETc) and net irrigation requirements (NIR) over the countries of former Yugoslavia and one part of the Mediterranean region for the period 2000-2050 (the reduction of ETc is expected in all areas actually suitable for cultivation while the positive values - blue coloured areas – indicate the zones which could be suitable for the cultivation in the future)

Finally, in the case of tomato, crop evapotranspiration is expected to decrease from 2% in Bosnia and Herzegovina to 6% in Croatia and Slovenia, whereas irrigation requirements could be reduced from 1% in Serbia to 7% in Slovenia. The foreseen ETc variation is in the range of expected average variation for the whole Mediterranean (5%) while NIR reduction could be likely lower in respect to the average foreseen reduction for the Mediterranean (7%). The results were in agreement with those obtained by other authors for other areas of the Mediterranean (Lovelli et al., 2010; Ventrella et al., 2012).

Conclusions

The impact of climate change of agricultural water requirements in the Balkan area is in agreement with the overall expectations for the Mediterranean region. The main effects of temperature rise would be: i) the expansion of cultivable land toward the Northern latitudes and higher altitudes; and ii) the extension of the season suitable for cultivation. This study pointed out that the increase of air temperature could contribute to a substantial shifting (anticipation) and shortening of crop growing cycle for most crops by the mid of this century. Hence, crop evapotranspiration and irrigation requirements could decrease especially for the winter-spring crops. This reduction of agricultural water needs could be greater for the countries of former Yugoslavia than for other areas of the Mediterranean. However, the perennial crops water requirements could remain the same or even increase due to reduction of precipitation. Consequently, the average water requirements of agricultural sector could be slightly lower or remain almost the same as today because it is expected that the shortening of the growing cycle could counterbalance the increase of evaporative demand and decrease of precipitation in the region. In any case, the impact of climate change could be distributed in a dissimilar way throughout the region due to spatial and temporal variation of future precipitation pattern and air temperature trend. As a result, the impact of climate change could increase gradually from the north-western areas of Slovenia towards southern Serbia and Macedonia.

Spontaneous adaptation to climate change through the anticipation of the sowing/planting dates for spring- summer crops is already adopted in many areas. On one side, it could keep almost unchanged ETc and NIR. However, on another, the anticipation of growing season increases the frost risk and reduces the intercepted photosynthetic active radiation (IPAR) with the negative effects on yield.

Overall effects of climate change on water productivity could be positive whereas the effects on yield could be seen within a complex interaction of different strategies including the starting of growing season, the selection of most adequate varieties (short/long maturing), and adopted locally-tailored (water, land and nutrient) management practices. Overall adaptive capacity of agriculture will depend also on a mutual link between the bio-physical factors and socio-economic and policy impacts including the changes in land, water, energy and food availability, population growth, migration and habits, market fluctuations, as well as the consideration of environmental services (FAO, 2012). The effect of adaptation measure should consider the adaptation capacity of each specific area and could have greater success where water (and economic) resources are plenty available. In fact, the availability of water resources represents one of the main advantages of the Balkan countries in respect to the rest of Mediterranean. Therefore, the adoption of sustainable site-specific agronomic practices and introduction of modern and efficient irrigation distribution systems should be a priority in order to reduce the risks of yield reduction in the future. This could be achieved only through the strong socio-economic and institutional setting, the accessible funding based on well-designed operative irrigation programs, the on-ground demonstration actions and the implementation irrigation projects especially in the most vulnerable areas of important agricultural regions.

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