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Full Length Research Paper

Prediction of climatic change for the next 100 years in Southern Italy

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This study investigates the impact of the expected climate changes in the Apulia region (Southern Italy) for the next 100 years on the climatic water balance variations, climatic classifications and crop water requirements. The overall results indicated that an increase of temperature, in the range between 1.3 and 2.5°C, is expected in the next 100 years. The reference evapotranspiration (ETo) variations would follow a similar trend; as averaged over the whole region, the ETo increase would be about 15.4%. The precipitation should not change significantly on yearly basis, although, a slight decrease in summer months and a slight increase during the winter season are foreseen. The climatic water deficit (CWD) is largely caused by ETo increase, and it would increase over the whole Apulia region in average for more than 200 mm. According to Thornthwaite and Mather climate classification (1957), the moisture index will decrease in the future, with decrease of humid areas and increase of aridity zones. The net irrigation requirements (NIR), calculated for ten major crops in the Apulia region, would increase significantly in the future. By the end of the 21st Century, the foreseen increase of NIR, in respect to actual situation, is the greatest for olive tree (65%), wheat (61%), grapevine (49%), and citrus (48%) and it is slightly lower for maize (35%), sorghum (34%), sunflower (33%), tomato (31%), and winter and spring sugar beet (both 27%).

Key words: Climate change, climatic water balance, climate classification, crop water requirements.

INTRODUCTION

Climate, through its major attributes or "variables" (temperature, precipitation, wind, etc.), exerts a strong influence upon all physical and biological aspects of the global natural environment and, in turn, is influenced to some extent by these same factors. Climate affects the types of soils being formed at the earth's surface, determines the geographical distribution of vegetation (and thus the distribution of animal life) and many human activities as well (e.g., agriculture, tourism, transportation,etc.).

Climate, in fact, changes continuously over time, because the different natural (cosmic, tectonic, oceanic, volcanic, etc.) and anthropogenic factors (land use, atmospheric pollution, etc.) contributing to its establishment are continuously changing. Thus, "climate change" (in the popular sense of the term) can be regarded as a variation from the "expected" climatic condition (Maunder, 1995).

Recent concerns about climate change have focused

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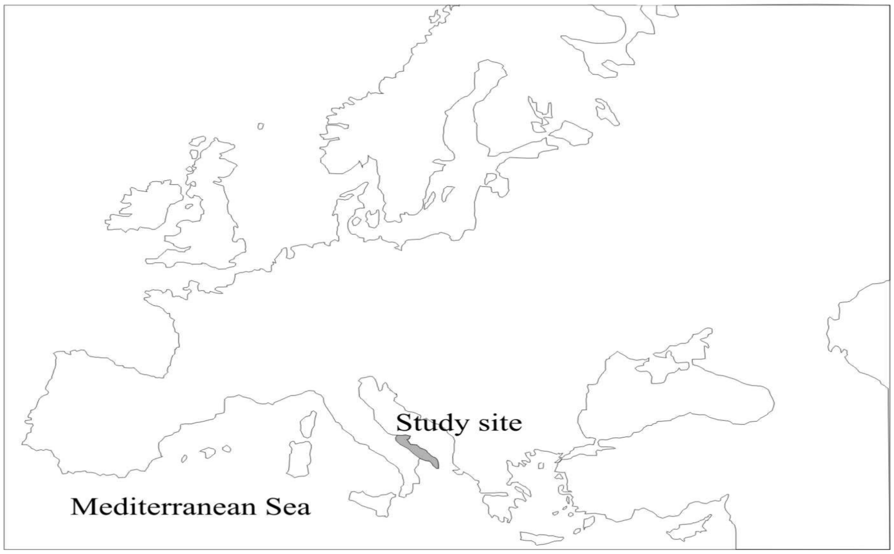


Figure 1. Location of study area.

on mankind's enhancement of the natural "change" through atmospheric pollution (mainly greenhouse gases), that modifies the composition of the atmosphere, which in turn "changes" the energy balance of the globe and pushes the resulting climate toward an expected "global warming". Nevertheless, in order to identify anthropogenic influences, contemporary changes in climate need to be placed in the context of much longer-term changes in climate that have taken place naturally in the past. In fact, only direct records of the climatic elements provide an inadequate perspective on climatic change and evolution of the climate today and in the future. A longer-term perspective on climate variability can be obtained from the study of natural phenomena which are climate-dependent.

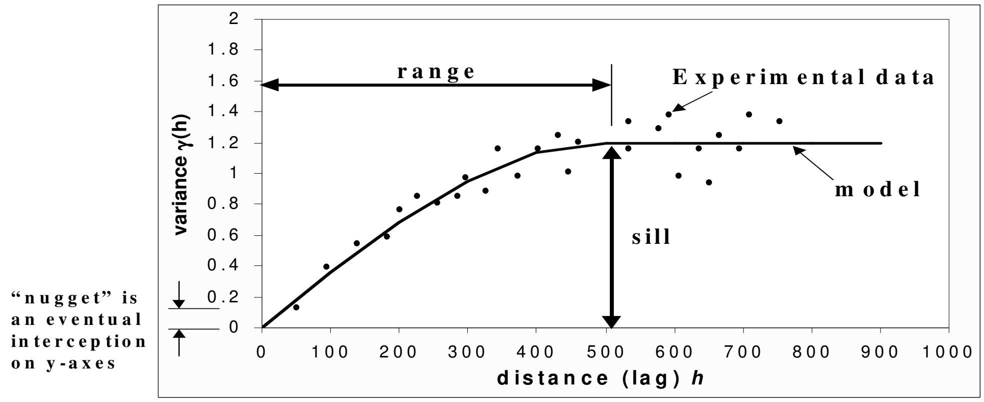
Over the past century or so, the Earth's surface and lowest part of the atmosphere have warmed up on average by about 0.5°C (Jones et al., 1999). During this period, the amount of greenhouse gases in the atmosphere has increased, largely as a result of the burning of fossil fuels for energy and transportation, and land use changes. In the last 20 years, awareness has grown that these two phenomena are, at least in part, associated to each other. That is to say, global warming is now considered most probably to be due to the man-made increases in greenhouse-gas emissions (Hansen et al., 1998). Whilst other natural causes of climate change, including changes in the amount of energy coming from the sun and shifting patterns of ocean circulation, which cause global climate to change over similar periods of time. These evidences clearly indicate that there is a discernible human influence on the global climate (Crowley, 2000).

The warming trend is expected to continue in the near future (about 2.5°C within the next 100 years) and with a strong concern on the impact that such change will have on the earth's ecosystems, human life and activities, in different regions of the planet. Patterns of agriculture, industry, human health and settlements, the natural environment, and land and water resources are all experiencing the effects of the expected climate change, and numerous studies have been, and currently are, underway to investigate the possible consequences and to devise measures to counteract the predicted undesirable outcomes (IPCC, 2001).

At the most general level, there is wide agreement that the impacts will be diverse. Some effects may be beneficial, while other effects may be counteracted through minimal adaptation. For the majority of people, however, the consequences of climate change will probably be negative and for some regions they could be disastrous. Accordingly studies of climate change and it's affects on future crop water requirements, relevant to the subject of this paper, bear utmost significance in determining, primarily the future of agriculture and it's countrywide policies. These policies will, most probably, contribute to the ultimate goal seeking to attain sustainability in the future climate and/or adaptability to future changes.

MATERIALS AND METHODS

The investigations reported here on the climate change and climatic water balance were carried out in the Apulia region, Southern Italy (Figure 1). The projected climatic change data for the period 1950 - 2100 were supplied by the UK Hadley Center for Climate change estimated by HadCM3, a coupled atmosphere-ocean general circulation model (GCM) developed by Hadley Centre for Climate Prediction and Research (UK). Many coupled ocean-atmosphere models have had a tendency to drift when simulating the climate of the present day (Collins et al., 2001). Such climate drifts are usually reduced by the use of flux adjustment (Sausen et al., 1988; Manabe



$$\gamma(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} \{Z(x_i) - Z(x_i + h)\}^2$$

Figure 2. The form of typical semi-variogram and semi-variance function where N is the number of pairs of sample points separated by distance h.

et al., 1991), whereby often large fluxes of heat and salinity are introduced at the interface between the ocean and the atmosphere components of the model. Such adjustments are clearly unphysical and to this end, there have been considerable efforts to build coupled ocean atmosphere GCMs that do not require these corrections. Such model has been built at the Hadley Centre at the UK Meteorological Office (Collins et al., 2001). HadCM3, the third version of the Hadley Centre coupled model requires no such flux adjustment and has a stable and realistic present day mean climate among the various GCMs (Gordon et al., 2000). The projected data estimated by this model are chosen because the HadCM3 has been run for the reconstruction of the past climate over thousands of years showing little drift in its surface climate over Europe. Moreover, this model has been used also by the Working Group of the Intergovernmental Panel on Climate Change for the realization of Special Report on Emissions Scenarios (SRES) and also in many other investigations (IPCC, 2001).

GCMs try to integrate the cyclic pattern of climate variation with the man-made change of atmospheric composition, combining the warming effects on global scale from increasing CO_2, and the regional cooling from the direct effect of sulfate aerosols. The data set applied in this work is based on the scenarios used by the Working Group of the Intergovernmental Panel on Climate Change for the realization of Special Report on Emissions Scenarios (SRES) which include the projections of how anthropogenic emissions of the greenhouse gases and other constituents will change in the future. In each SRES scenarios, different levels of world development, including population growth, economic growth, energy and technology use and different levels of SO_2 emissions in the future. In this study the A2 SRES scenario is applied, which assumes a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in continuously increasing population. Economic development is primarily regionally oriented and per capita economic growth and technological change are more fragmented and slower than in other storylines (IPCC 2001).

The initial set of historical weather data for 162 locations within the study area was taken from the Italian National Hydrographic Institute. Several methods for data processing, including spatial interpolation techniques, climate classifications, estimation of climatic water deficit and irrigation requirements were applied in this work.

Monthly temperature and precipitation data measured at the 162 meteorological stations over a period of 40 years (1950 - 1990) formed the initial database, which was later extended to include the period 1990 - 2100 on the basis of the expected climate changes estimated by HadCM3. The downscaling from global to regional scale was performed on monthly data averaged on a 10-years basis.

The Kriging method was applied for the spatial interpolation of weather variables. This is a stochastic optimal interpolation method, frequently used for interpolation of both weather and soil variables. In recent decades, the Kriging has become a very popular interpolation method, due to its advantageous properties; each estimate is supplied with confidence information in which the quantified uncertainty increases with the distance from the observation points; an estimated spatial picture of a variable links up continuously with the observations at the observation points; it is a statistical method of which statistical tests (variances of the parameter estimates) can be derived; Kriging provides a measure of uncertainty of the estimated surface; the technique is powerful and can be easily programmed. The Kriging interpolation technique is based on the statistical theory of random functions. A random function can be defined as a theoretical function which provides for each given space location the statistical distribution of values that may occur. This observed values constitute what will be called the realization of the random function in certain space locations. All calculations aim at building the best possible image of this random function on the basis of all observed values. The input data at known locations are used for the derivation of semi-variogram representing usually an irregularly spaced sample of points. The basis of the Kriging technique is the rate at which the variance between points changes over the space. This is expressed through the semi-variogram (Figure 2) which shows how the average difference between values at points changes with the distance between the points.

Mathematical curves (models) have to be fitted through the experimentally derived data points in order to describe the way in which semi-variance changes with the distance. The choice of the model to be used for interpolation is performed by the user by examining the behavior of these mathematical models representing the semi-variograms. The model parameters are unknown, a priori and different for each variables and couple of variables. The values of these parameters may be obtained by weighted least-squares method or using the method of maximum likelihood. The most frequently used models of semi-variogram are: Spherical model, Exponential model, Gaussian model, Linear model, Power model. Although most steps are performed automaticly in GIS, the user of system decides on the model of semi-variogram to be apply for interpolation. Choosing among different models should rely on statistical consideration, studies variables and the purposes of the work. The user must strike a balance between the goodness of fit and parsimony of his model. In general, it is important that the semi-variogram is well estimated at short distances and the user should choose the model that fits well in this region of the semi-variogram. Interpolation values are the sum of the weighted values of some number of known points, where weights depend on the distance between the interpolated and known points and the model of semi-variogram chosen for interpolation. Weights are selected so that the estimates are: Unbiased, by imposing conditions that the sum of weights is one, Optimized by imposing condition that the variance of estimation error is minimum. Finally, the estimated values are nothing more than linear combination of the observed values and weights attributed to them.

For both the array of meteorological stations and the grid cells of the HadCM3 model, reference evapotranspiration (ETo) was estimated by the Hargreaves method (Hargreaves and Samani, 1985) since the input data set includes only T_{max} and T_{min}. The reference evapotranspiration was calculated on a monthly basis. Previous investigations in the region have demonstrated that the use of the Hargreaves method yields more realistic values than the Blaney-Criddle method.

The Hargreaves method is a simple empirical equation which uses the values of extraterrestrial radiation (R_a) as an input, in addition to the minimum and maximum air temperatures (T_{min} and T_{max}, respectively). The following form of the Hargreaves equation was applied:

$$ET_o = 0.0023 \frac{R_a}{\lambda}(T + 17.8)(T_{\max} - T_{\min})^{0.5} \quad (1)$$

where λ is the latent heat of vaporization. T is an average temperature in °C, calculated as:

$$T = \frac{T_{\min} + T_{\max}}{2} \quad (2)$$

and where the multiplier (0.0023), the exponent (0.5), and the value of 17.8 in the third multiplier of the equation, are constant values determined empirically.

The Climatic Water Deficit (CWD) then could be calculated on monthly basis as a difference between reference evapotranspiration (ETo) and precipitation (P):

$$CWD = ET_o - P \quad (3)$$

The Net Irrigation Requirements (NIR) were then calculated on a monthly basis for ten selected crops, widely cultivated in the Apulia Region, namely: Citrus fruits, olives, grapes, winter sugar beet, spring sugar beet, wheat, sun-flower, maize, tomato and sorghum.

The Crop Water Requirements were calculated through a two step approach:

$$ET_c = ET_O \times K_c \quad (4)$$

where ET_c is standard crop evapotranspiration (mm/day), K_c is crop coefficient and ET_o is reference evapotranspiration, (mm/day).

The Kc values used were derived from experimental work carried out by the University of Bari.

The Effective rainfall was calculated for the whole area from:

$$Peff = P \times 0.8 \quad (5)$$

Finally the NIR is calculated for every month during the growing seasons as:

$$NIR = ET_c \times P_{eff} \quad (6)$$

In the analysis, the Kc values at the beginning and the end of the growing season were assumed to remain constant for the next 100 years.

The method of Thornthwaite and Mather (1957) was applied for the climate classification of the Apulia region. Thornthwaite and Mather (1957) introduced the most relevant humidity (and aridity) index that involves a comparison of the amount of water added to a particular climatic region (P) not with average temperature (T) but directly with the existing or potential water content of that climatic region. This approach represented a major evolutionary step in climatic classification and required the introduction of a new climatic element, that is, the potential evapotranspiration (ETP), representing the evaporative demand of the atmosphere, and here termed the reference evapotranspiration (ETo).

Once the ETo is determined, two basic variables can be derived: (1) The deficit (d) when P < ETo, and (2). The excess (w) when P > ETo. Then, the aridity (Id) and the humidity (Iw) indices of Thornthwaite can be defined as:

$$Id = \frac{d}{ETo} * 100 \quad (7)$$

and

$$Iw = \frac{w}{ETo} * 100 \quad (8)$$

Subsequently, Thornthwaite and Mather (1957) combined these two indices within a global moisture index (*Im*) calculated from:

$$I_m = \frac{P - ET_O}{ET_O} \times 100 \quad (9)$$

The index *Im* is positive for humid climates (w > d) and negative for arid climates (w < d). This index is a critical component in the climatic classification of Thornthwaite and Mather (1957), where it is linked to other expressions.

The global moisture index *Im* thus provides a valuable measure of the aridity or humidity of a given region, the major climatic classes defined by Thornthwaite and Mather (1957) being based on his moisture index (Table 1).

In addition to this aridity/humidity grouping, it is also necessary to consider the average temperature and how this may be grouped. For this aspect, Thornthwaite concentrates on the thermal requirement of vegetation, thus introducing the thermal efficiency index as a function of the annual ETo which, in turn, is an expression of the water requirements for plant growth (In one sense, ET is linked to T, and then T is linked to growth). The additional notation to identify climatic groups thermally, making use of the thermal efficiency index, is given in Table 2.

RESULT AND DISCUSSION

An overall increase of global temperature, in the range

Table 1. Major climatic classes according to the moisture index of Thornthwaite and Mather (1957).

Climatic classes	Climatic description	I_m range
A	Hyperhumid	>100
B_4	Humid	80-100
B_3	Humid	60-80
B_2	Humid	40-60
B_1	Humid	20-40
C_2	Humid/subhumid	0-20
C_1	Subhumid/subarid	-33.3-0
D	Semiarid	-66- -33.3
E	Arid	-100- -66.6

Table 2. The Thermal efficiency symbols and descriptions, according to the Thornthwaite and Mather (1957) classification.

Symbol	ETo ranges (mm)	Climatic Group
A'	> 1440	Megathermic
B_4'	1440 - 997	Fourth mesothermic
B_3'	997 - 855	Third mesothermic
B_2'	855 - 712	Second mesothermic
B_1'	712 - 570	First mesothermic
C_2'	570 - 427	Second microthermic
C_1'	427 - 285	First microthermic
D'	285 - 142	Tundra
E'	< 142	Frost

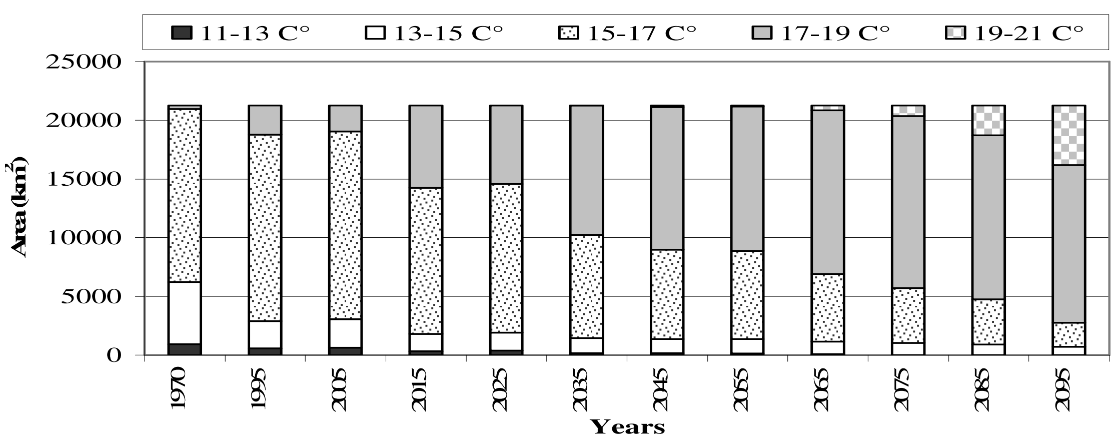


Figure 3. Histogram representing the variation of temperature in the region.

between 1.3 and 2.5°C, is expected over the next 100 years within the Apulia region, the area of land experiencing average annual temperatures ranging between 15 and 17°C would decline from the current value of more than 60% to less than 10% by the end of the present Century. An increase of the area with the temperature range of 17 - 19°C is foreseen, from a few percent (present situation) to more than 60% (for the decade 2090 - 2100). Those areas with an average annual temperature in the range of 13 - 15°C will almost completely disappear (from 30% at present to 4% in 2091-2100) and the areas with temperature between 19 and 21°C will increase from less than 1% in the middle of the 21st century to almost 20% by the end of Century. Figure 3 represents the variation of temperature in the region depending on area basis. The results are similar to

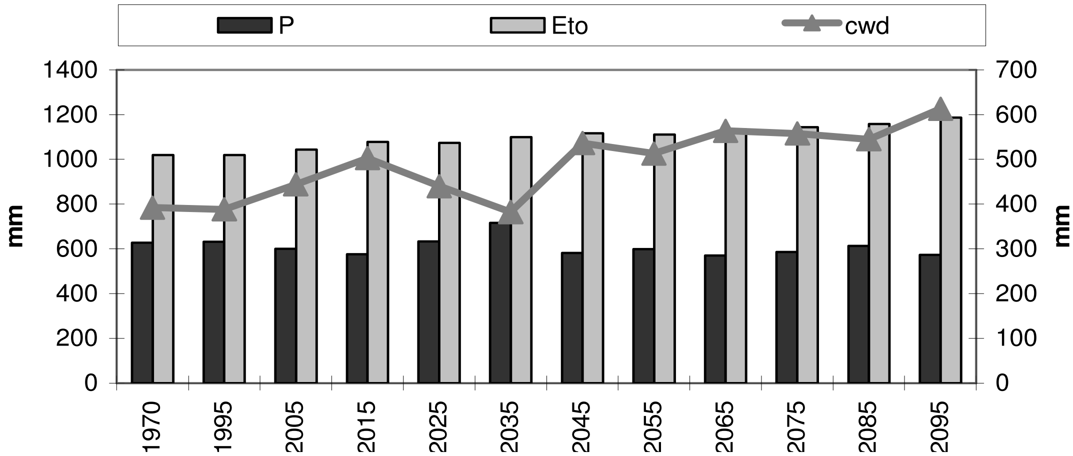


Figure 4. Average variation of precipitation (P), ETo and CWD (Climate Water Deficit) in the Apulia region for the period 1950 - 2100.

the projected percentage changes of temperature in the Edwards Aquifer region of Texas, where the Hadley Centre for Climate Prediction and Research predicts an increase in temperature of about 9% over the next 100 years (Chen et al., 2001). The foreseen temperature changes in our study area for the same period, fall within the same range, as also in a study conducted in Israel where mean temperatures are predicted to increase between 1.6 - 1.8°C over the next 100 years (Pe'er and Uriel, 2000).

The ETo variations follow a trend similar to those forecast for temperature. In fact, when averaged over the whole region, the foreseen increase of ETo would be about 15.5%. An enhanced ETo is foreseen for almost every month, with the peaks observed in June and July of more than 25 mm/months. These results demonstrate that at present, most of the Apulia region (between 70 and 80%) lies within the range 1000 - 1200 mm but the surface area displaying this Eto range will probably decrease. Moreover, it is expected that the small area presently characterized by ETo values between 900 and 1000 mm will completely disappear, while a strong expansion of the areas with Eto values in the range 1200 – 1300 mm is foreseen, especially in the second part of the 21st century. In some other investigations, researchers have predicted that the potential evapotranspiration may increase by 30% by the year 2100 (for example in central Poland: IUCC, 1994), whereas, this study indicates that over the next century the evapotranspiration may increase by 35%. A study of Southern Africa, utilizing published model scenarios for 2050 and following standard IPCC methodology, reported that evapotranspiration may increase between 5 and 10% over the next 50 years (Sherman, 1992), whereas, in this study, evapotranspiration in Apulia is foreseen to increase by 4% by 2050. According to Pe'er and Uriel (2000) the overall temperature increase of 1.5°C in the Mediterranean basin, anticipated in Israel around 2100, and is expected to enhance evapotranspiration rates by 10% (Jeftic, 1993). In the present study, over the next century the temperature is predicted to increase by 2°C and evapotranspiration is enhanced by up to 11%.

The anticipated climatic water deficit (CWD) increase is largely caused by these enhanced ETo values and over the next 100 years CWD in the Apulia region is calculated to increase on average for more than 200 mm (Figure 4). This trend is most marked for the period 2060 - 2100, when the water deficit is predicted to fall in the range of 600 - 800 mm over most of the region, while in the last decade (2090 - 2100) in some areas, the CWD would increase to 905 mm. Over the next century, the areas with CWD in the range 600 - 800 mm are expected to increase from only a few percent to more than 50%. The total surface area with water deficits between 300 and 500 mm will also decline from the present value of 65 - 15% by the end of the 21st Century (Figure 5). Moreover, by that date, it is expected that the total area displaying water deficit values greater than 800 mm will represent about 10% of the study region. Some other investigations of the effects of climate change (GEO, 2000) have reported results indicating that in the Arabian Peninsula, for example, the annual climate water deficit could increase to 67% of the actual demand by 2015. Nevertheless, from our study, the climate water deficit of the entire Apulia territory in the same period may increase by 30%.

The moisture index will decrease in the future, resulting in a decrease in areas classified as humid and enlargement of the arid zones (Figure 6). The areas presently classified as subhumid/subarid will be characterized as semiarid zones by the end of the 21st Century. In fact, it is expected that the total regional area converted from a subhumid/subarid to a semiarid climate will be about 15% of the Apulian territory. Moreover, in those areas predicted to fall within the arid climate category, the Eto values will be three times higher than

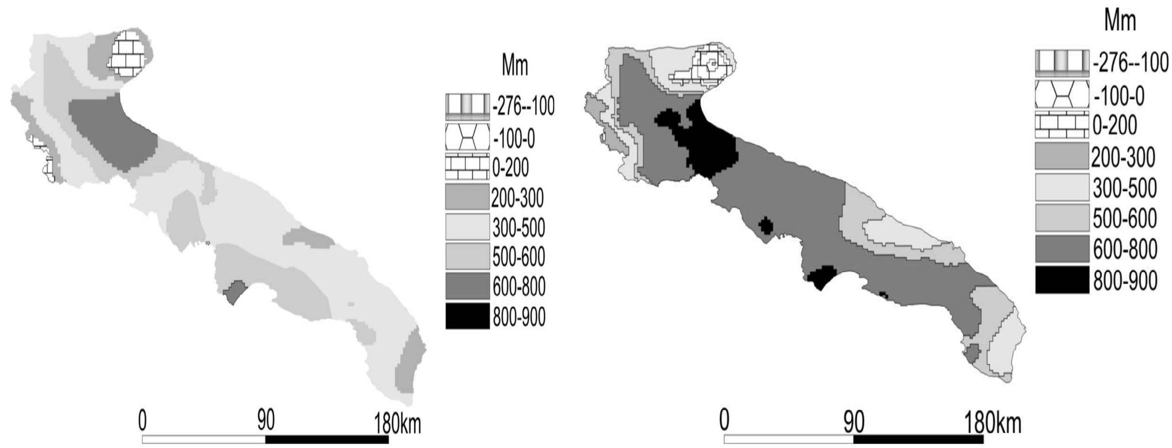


Figure 5. Climate water deficit maps of Apulia region. A. For the years 1950 - 1990. B. For the years 2091 - 2100.

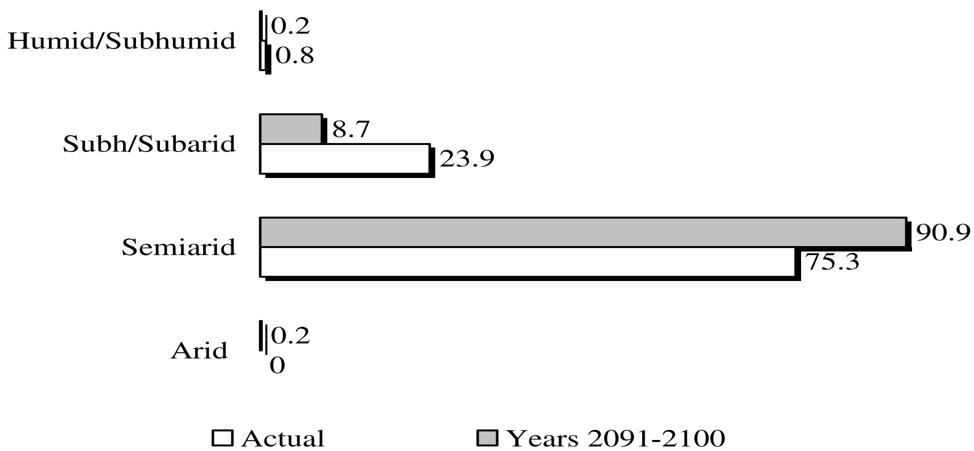


Figure 6. Climatic classes as percentage of the Apulia region at the present time and by the end of 21st century.

the precipitation. However, these specific climatic conditions probably will occur in only a few limited zones with a total surface area of less than 50 km^2.

According to the Thornthwaite classification, three climatic groups are currently represented in the region (second, third and fourth mesothermic). However, by the end of this century only two of these are likely to remain, while the second mesothermic group will have disappeared completely. In fact, the foreseen increase in Eto will also enhance thermal efficiency and thus will shift the relevant graphs from second and third mesothermic to fourth mesothermic. A large expansion of the fourth mesothermic group is thus predicted and, by the end of this century, this category could represent 98.5% of the Apulian territory, compared to about 73% of the region under present-day conditions. This means that the annual ETo would be greater than 997 mm in 98.5% of the region, while at any other location in the Apulia region it would be greater than 855 mm.

This study also has demonstrated that the net irrigation requirements (NIR) for the ten major crops of the Apulia territory will increase significantly in the future. The predicted increase of NIR by the end of the 21st Century is highest for olive trees (65%), followed by wheat (61%), grapevines (49%) and citrus crops (48%), whereas, it is slightly lower for maize (35%), sorghum (34%), sunflower (33%), tomato (31%), winter and spring sugar beet (both 27%) (Figure 7). In almost all cases, the highest increase of NIR is foreseen for those months when the crops are the most sensitive to water stress, with significant negative consequences for their growth. These results agree closely with those obtained in Southern Africa for the Malibamatsama basin, 3240 km^2 in Lesotho where the main irrigated crops are wheat, cotton, maize, tea and sugar beet. Climate change simulations for this region have been obtained using a general circulation model that involves a doubling of CO_2 and the results reveal a 65% increase in irrigation water demands over the next

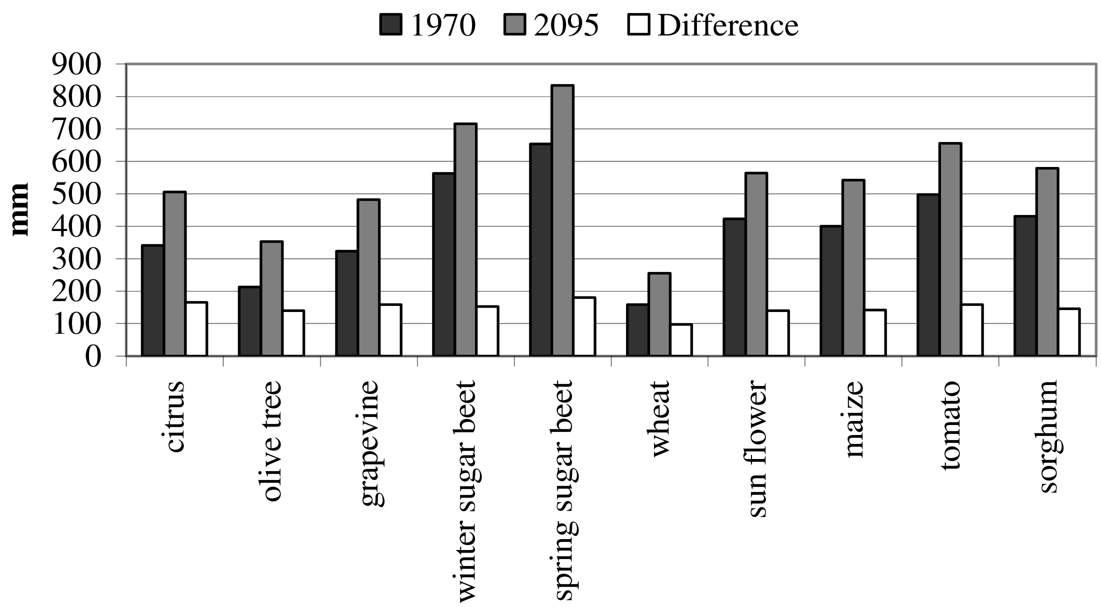


Figure 7. Annual NIR of ten major crops in the Apulia region.

50 years (Sherman, 1992). Nevertheless, in the present study the net irrigation requirement for wheat, maize and sugar beet could increase by an average of 42% over the next 100 years.

A study of the Texas Edwards Aquifer (Chen et al., 2001) reported that, under the Hadley Centre simulator scenario, by the year 2090 the irrigation water requirement for maize will increase by 31.32%. According to our study, the water requirement of maize in the Apulia region will increase by 35% over the same time period (Figure 7).

Conclusions

The results obtained in this work indicated that an increase of temperature and ETo and a reduction of precipitation (with concentration in winter period) is expected in the future. These results largely coincide with the results of some other analysis on climate changes in the Mediterranean region (Jeftic, 1993; Pe'er et al., 2000) and also in some other areas (Ryszkowski and Kedziora, 1991). The magnitude of these changes varies locally and it would have significant influence on the climatic water deficit in the region and could contribute to further aggravation of the situation related to agricultural production in the Apulia region. In fact, the trend of variation of climatic variables may increase crop water demand and reduce volume of water in the water supply systems. Moreover, higher temperatures may lead not only to the crop water stress but also to the crop heat stress and decrease in crop growth and yield productivity especially for crops with specific temperature requirements, such as corn, soybeans and wheat. Also, the periods with temperature above average seasonal values may influence the expansion of agricultural pests and/or the acceleration of their life cycle. In fact, it is foreseen that growing period of many field crops would shift for a couple of weeks anticipating initial stage. Also, in some cases, due to higher temperatures during the growth, a decrease of growing cycle and anticipated maturation could be expected.

One of the main scopes of this study on climate change is to assess if water resources will be sustainable for agricultural production. Sustainability will be most influenced by adaptive responses. In addition to increasing CWD and NIR, another factor could create problems such as limited water resources for crop production. For this reason some adaptation options must be considered to face the future problems of water shortage.

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