A broad overview of the main problems derived from climate change that will affect agricultural production in the Mediterranean area

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EXECUTIVE SUMMARY

Climate change refers to present and future changes in climate conditions and is more frequently reflected by increasing average temperature, changes in precipitation and changes in the frequency, intensity, spatial extent, duration and timing of extreme weather and climate events. The Mediterranean region presents wide climate variability but the collective picture is one of substantial drying and warming. Especially in the warm season, precipitation decrease may exceed –25 to –30 percent and warming may exceed 4–5 °C. Extreme events in the Mediterranean region are related to droughts and floods that may give rise to deep erosion and landslides. For these reasons, the Mediterranean region is identified as one of the most prominent hotspots in future climate-change projections. Climate change is assumed to have significant effects on Mediterranean agriculture. Projected climate changes will have a direct impact on water resources and irrigation requirements, crop growth conditions, crop productivity and crop distribution, agricultural pests and diseases, and the conditions for livestock production. These impacts will generate changing land-use patterns and will trigger economy-wide effects.

In the Mediterranean parts of Europe, the declining water balance has been documented over the past 32 years. In certain North African and eastern Mediterranean countries, climate change may result in surface water reductions of more than 35 percent. Rainfed agriculture, which, in certain areas of North Africa represents more than 90 percent of total agricultural land, will be particularly affected. Crop growth will be directly affected by climate change. In southern Europe, general decreases in yield (e.g. legumes –30 to +5 percent; sunflower –12 to +3 percent and tuber crops –14 to +7 percent by 2050) and increases in water demand (e.g. for maize +2 to +4 percent and potato +6 to +10 percent by 2050) are expected for spring-sown crops. However, in the warmer southern Mediterranean, increases in CO_2 will help reduce the loss in yield arising from a warmer and drier climate, but will not be able to recover the losses completely. In the cooler northeastern Mediterranean, CO_2 increases

associated with climate change will result in little net effect on most crops, provided that the increase in water demand, especially for irrigated crops, can be met. The change in land productivity brought by changing climate conditions may trigger economy-wide effects. In areas with significant productivity losses such as the Mediterranean south and with the agricultural sector still playing a significant role in the overall economy, gross domestic product (GDP) changes are expected to be negative and significant, especially under the A2 scenario.

Climate change will apply an additional stress on rates of land degradation through changes in the length of days and/or seasons, recurrence of droughts, floods and other extreme climatic events, changes in temperature and precipitation, which in turn reduces vegetation cover, water resource availability, soil quality and changes in land-use practices, such as conversion of land use, pollution and depletion of soil nutrients. The impacts of climate change on storm runoff and erosion in Mediterranean watersheds are difficult to assess owing to the expected increase in storm frequency coupled with a decrease in total rainfall and soil moisture, added to positive or negative changes to different types of vegetation cover. However, the most serious effect of climate change and especially of increased temperatures and summer droughts on forest is expected to be the risk of forest fires. Depending on the scenario, it is expected that in southern Europe, climate change will increase forest fires by 10–20 percent.

Resilience refers to actions aiming at building tolerance against the effects of global warming. At farm level, resilience actions include the adoption of drought-resistant crops, the adoption of water-saving cropping methods such as mulching, minimum tillage and maintenance of cover crops, a change in planting dates and cultivars, and even a shift to cropping zones by altitude and latitude. Resilience at farm level should be coordinated and planned to avoid possible internal incoherencies among resilience measures and inconsistencies of resilience with wider rural development objectives. Certain resilience measures are contradicting water conservation objectives while other resilience measures can be better coordinated in the framework of wider objectives such as the soil and water conservation strategies. Taking into account the specificity and diversity of the socio-economic conditions in the Mediterranean basin together with the fact that this region of the world is considered to be a climatic change hotspot, building a resilience strategy is a priority, “no regret” action.

1. INTRODUCTION

The aim of this paper is to provide a broad overview of the main problems that will affect agricultural production in the Mediterranean area and are derived by climate change. In this section, the scientific ground of this work is set by presenting the basic definitions and the scientific evidence of the expected significant climate change in the Mediterranean area. In section 2, we provide an overview of potential climate change impacts on agriculture in the context of the Mediterranean area. Section 3 analyses the relationships between climate change, soil erosion and subsequent desertification problems. Section 4 considers the potential impact of climate change on Mediterranean forest with special reference to forest fires, not only on forests but also the important agro-forest systems characterizing this region of the world. Finally, section 5 analyses the strategies that build resilience to climate change in agriculture in the Mediterranean region, while section 6 presents the basic conclusions of this critical review of the literature.

1.1 Definitions and the climate change framework

Climate change is an issue of world importance not only because it affects the global physical environment but also because its consequences will spread through planetary economic and social mechanisms to every nation irrespective of the local severity of impacts. A broad definition of climate change is adopted by the Intergovernmental Panel on Climate Change (IPCC), the leading international body for the assessment of climate change. Climate change in IPCC usage refers to a change in the state of the climate that can be identified (e.g. using statistical tests) by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer. It refers to any change in climate over time, whether as a result of natural variability or as a result of human activity (IPCC, 2007a). A narrower definition is adopted by the United Nations Framework Convention on Climate Change (UNFCCC), where climate change refers to a change of climate that is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and that is in addition to natural climate variability observed over comparable time periods. In this work we adopt the IPCC definition of climate change and we accept the scientific evidence provided in IPCC's Third Assessment Report (TAR) and Fourth Assessment Reports.

Climate change refers to present and future changes in climate conditions. Present changes are based on observed scientific facts, while future changes are based on projected simulations under various scenarios. Ambiguity rises because of the frequently interchangeable use of these two terms. As concerns the present state, the IPCC is definite by stating that "Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice and rising global average sea level" (IPCC, 2007a). As a result, the observed climate changes have already produced a series of evident effects and a range of hypothesized effects. As the IPCC states "Observational evidence from all continents and most oceans shows that many natural systems are being affected by regional climate changes, particularly temperature increases" while "other effects of regional climate changes on natural and human environments are emerging, although many are difficult to discern due to adaptation and non-climatic drivers" (IPCC, 2007a).

Taking into account the chain from greenhouse gas (GHG) emissions to atmospheric concentration, to radiative forcing and climate responses and effects, projections of the future are, primarily, based on scenarios about the likely evolution of GHG emission. The Special Report on Emissions Scenarios (SRES) has devised four families of likely future development pathways (A1, A2, B1 and B2) that include a wide range of demographic, economic and technological driving forces and their consequent GHG emissions but do not include climate policies above current ones. Each one of the four families of scenarios assumes a storyline concerning the likely evolution of demographic, economic and technological parameters. Short- and long-term assessments of future climate change are based on the underlying assumptions of these families of scenarios. Thus, when discussing about future climate change, one should be clearly aware of the underlying hypotheses used to produce such projections. Therefore, it is important to present, very briefly, the hypotheses of the four broad families of scenarios in the words of the SRES.

The A1 scenario adopts a storyline that assumes a world of very rapid economic growth, a global population that peaks in mid-century and rapid introduction of new and more efficient technologies. A1 is divided into three groups that describe alternative directions of technological change: fossil intensive (A1FI), non-fossil energy resources (A1T) and a balance across all sources (A1B). B1 describes a convergent world, with the same global population as A1, but with more rapid changes in economic structures towards a service and information economy. B2 describes a world with intermediate population and economic growth, emphasizing local solutions to economic, social and environmental sustainability. A2 describes a very heterogeneous world with high population growth, slow economic development and slow technological change. Also, it is important to note that there is no likelihood attached to any of the SRES scenarios. The influence of these assumptions on the variability of projected global average surface warming and sea level rise by the end of the twenty-first century is very significant. Relative to a 2000 Atmosphere-Ocean General Circulation Model (AOGCM) base, temperature may rise from a low 1.8 °C for the B1 family of scenarios to 4 °C for the A1FI scenario, while the corresponding ranges for sea level rise are from 18 cm to 59 cm (IPCC, 2007b).

Furthermore, a changing climate leads to changes in the frequency, intensity, spatial extent, duration and timing of extreme weather and climate events, and can result in unprecedented extreme weather and climate events. Thus, future climate-change projections deal with the occurrence and intensity of extreme events that, very frequently, lead to physical disasters. The relationship between climate change and extreme weather and climate events may have severe implications on society and sustainable development, depending not only on the extremes themselves, but also on exposure and vulnerability. According to SREX, climate extremes are defined as "The occurrence of a value of a weather or climate variable above (or below) a threshold value near the upper (or lower) ends of the range of observed values of the variable. For simplicity, both extreme weather events and extreme climate events are referred to collectively as climate extremes" (IPCC, 2012). Some of the expected extreme events are absolutely related to agriculture and forestry and for this reason we present, briefly, the preliminary statements by SREX. First, the SREX states that "It is *virtually certain* that increases in the frequency and magnitude of warm daily temperature extremes and decreases in cold extremes will occur in the 21st century at the global scale. It is *very likely* that the length, frequency, and/or intensity of warm spells or heat waves will increase over most land areas. Based on the A1B and A2 emissions scenarios, a 1-in-20 year hottest day is *likely* to become a 1-in-2 year event by the end of the 21st century in most regions, except in the high latitudes of the Northern Hemisphere, where it is *likely* to become a 1-in-5 year event". Second, the SREX states that "It is *likely* that the frequency of heavy precipitation or the proportion of total rainfall from heavy falls will increase in the 21st century over many areas of the globe". And is very important to note that "...in some regions, increases in heavy precipitation will occur despite projected decreases in total precipitation in those regions" (IPCC, 2012).

In closing this section we should note that for all aforementioned evidence and future projections for global climate change in general, and for the European climate change specifically, substantial uncertainties remain. Although wide-ranging impacts of changes in current climate have been documented in Europe with very high confidence, uncertainties remain and reflect the sensitivity of the European climate change to the magnitude of the global warming and the changes in the atmospheric circulation and the North Atlantic ThermoHaline Circulation (THC) or, in general, the Atlantic Meridional Overturning Circulation (MOC). Deficiencies in modelling the processes that regulate the local water and energy cycles in Europe introduce uncertainty, for both the changes in mean conditions and extremes. For example, uncertainties emerge from model results that, while agreeing on a large-scale decrease in summer half-year precipitation in South Europe, disagree on the magnitude and geographical details of this change in precipitation patterns. Finally, uncertainty is introduced by the significant natural variability of the European climate.

1.2 The Mediterranean area as a climate change hotspot

Owing to the fact that the Mediterranean region lies in a transition climate zone between North Africa and central Europe, it is affected by mid-latitude and tropical processes. The Mediterranean region is also characterized by a complex topography, the presence of a large water body, extensive coastline and vegetation that modulate regional climate signals at small spatial scales. The Mediterranean region also may be influenced by GHG emissions of central Europe, Africa and Asia (Alpert *et al.*, 2006). All the aforementioned factors contribute to a climate of highly diverse types and significant spatial variability.

Concerning present changes to climatic conditions, and according to the National Oceanic and Atmospheric Administration (NOAA), wintertime droughts are increasingly common in the Mediterranean region, and human-caused climate change is partly responsible for this. In the last 20 years, ten of the driest 12 winters have taken place in the lands surrounding the Mediterranean Sea. NOAA (2011) found agreement between the observed increase in winter droughts and in the projections of climate models that include known increases in greenhouse gases. Both observations and model simulations show a sudden shift to drier conditions in the Mediterranean beginning in the 1970s. The analysis began with the year 1902, the first year of a recorded rainfall dataset. Figure 1 summarizes the findings of the NOAA study. As concerns future changes, the IPCC's assessment of projected climate changes in Europe states that annual mean temperatures in Europe are likely to increase more than the global mean and that the warming in the Mediterranean area is likely to be largest in summer (Christensen *et al.*, 2007). The same report acknowledges that the annual precipitation is very likely to decrease in most of the Mediterranean area, while the annual number of precipitations is very likely to decrease and the risk of summer drought is likely to increase. In addition to these changes, the likely occurrence of extreme events, including extreme precipitation or extreme lack of precipitation with high temperature, is expected to increase, leading to high-impact floods and droughts (Kundzewicz, Radziejewski and Pi´nskwar, 2006). Giorgi and Lionello (2008) present the most comprehensive and updated review of climate-change projections over the Mediterranean region based on global and regional climate-change simulations. Figure 2

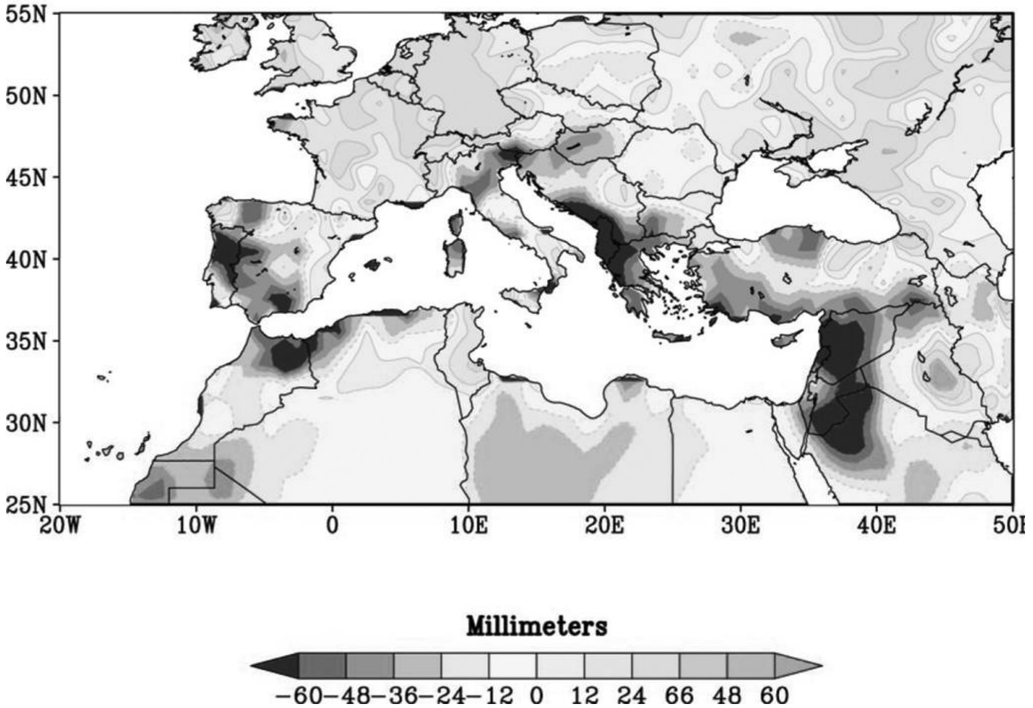

Figure 1. Greyscales highlight lands around the Mediterranean that experienced significantly drier winters during 1971–2010 than the comparison period of 1902–2010
Source: NOAA (2011).

summarizes Giorgi and Lionello's (2008) findings by European subregions including the Mediterranean area. It is evident that the Mediterranean region presents a wide variability but the collective picture is one of substantial drying and warming. Especially in the warm season, precipitation decrease may exceed –25 to –30 percent and warming may exceed 4-5 °C (Giorgi and Lionello, 2008). Taking a closer look at subregions we realize the significant variability in projections of winter and summer precipitation and air temperature corresponding minimum and maxima.

Hertig and Jacobeit (2008a) found that "temperatures show an increase for the whole Mediterranean area and for all months of the year in the period 2071–2100 compared to 1990–2019 under the B2 scenario conditions, ranging mostly between 2 and 4 °C, depending on region and season". The same authors underlined that: "Even though there is still a high degree of uncertainty regarding the regional distribution of climate change in the Mediterranean area, substantial temperature changes of partly more than 4 °C by the end of this century have to be anticipated under enhanced greenhouse warming conditions." As concerns precipitation, Hertig and Jacobeit (2008b) found that: "under the B2 scenario conditions, a shortening and at the same time an increase in rainfall amount of the wet season arises for the western and northern Mediterranean regions" and "Precipitation increases in winter for the period 2071–2100 compared to 1990–2019, whereas precipitation decreases dominate in autumn and spring. The eastern and southern parts of the Mediterranean area,

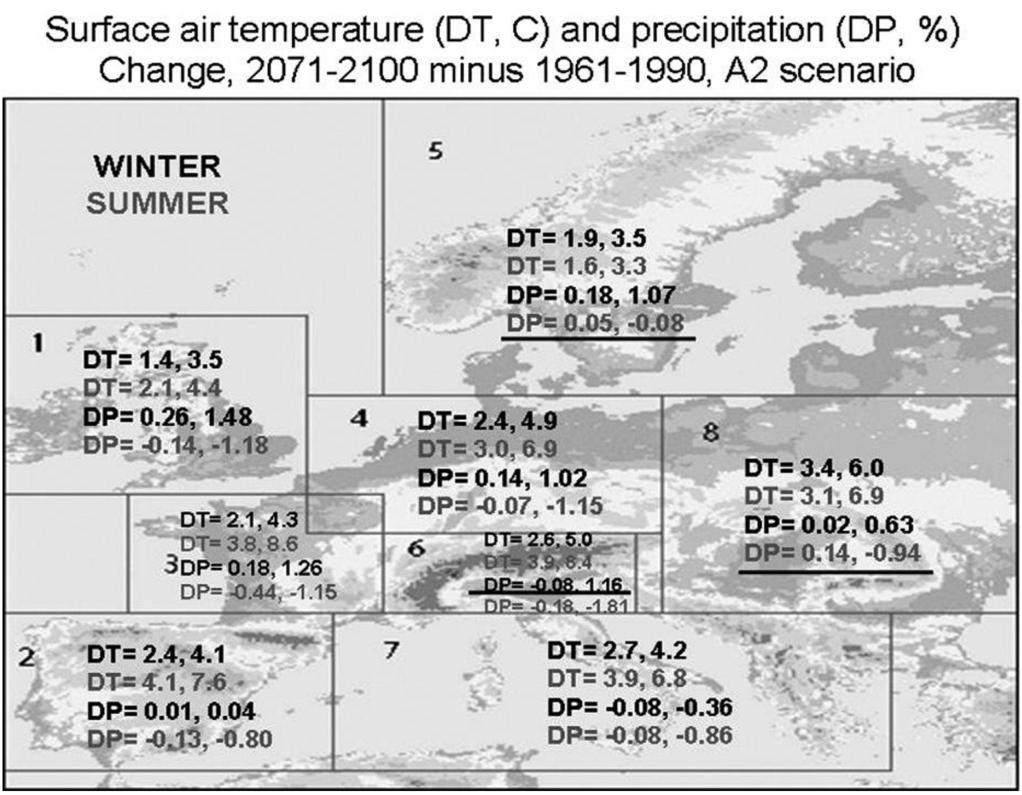

Figure 2. Minimum and maximum change in surface air temperature (DT) and precipitation (DP) simulated by the ensemble of global and regional climate models in the PRUDENCE project over different PRUDENCE subregions (land only points), 2071–2100 minus 1961–1990, A2 scenario.
Units are °C for temperature and mm/day for precipitation.
Source: Figure 15 in Giorgi and Lionello (2008).

on the other hand, exhibit mainly negative precipitation changes throughout the period from October to May, under enhanced greenhouse warming conditions."

In North Africa and the Saharan regions, annual mean temperatures are expected to increase by median values of 3.5 and 3.6 °C, respectively, for the A1B scenario, with the largest increases expected during the summer months of June, July, and August (NIC, 2009). Concerning precipitation, the projections are less definitive for North Africa but involve a drying trend, especially along the Mediterranean coast, that is expected to become more pronounced with time. Paeth *et al.* (2009) estimate that by 2050 surface temperatures in North Africa will increase by approximately 1.5 to 2 °C and precipitation will decrease by 10 to 30 percent across many of the desert areas of the region, with larger precipitation decreases of up to 200 percent along the coasts of Morocco, Algeria and Tunisia. Similar projections prevail for the southeast Mediterranean region including Israel, Lebanon, Cyprus and parts of southwest Turkey.

Giorgi and Lionello (2008) also review the likely occurrence of extreme events and conclude that "High temperature extremes and drought events were found to increase substantially in summer while winter low temperature extremes were found to decrease"

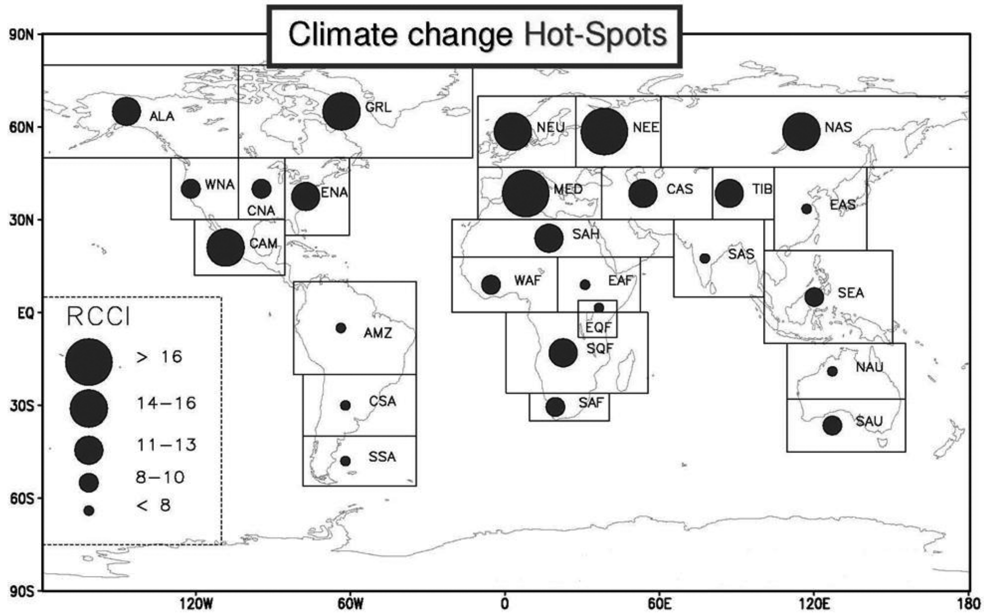

Figure 3. Climate change hotspots
Source: Giorgi (2006).

while, "On a yearly basis, a prevailing increase in precipitation extremes over the Mediterranean was found, particularly over and around the Alpine region". Thus, extreme events are related to droughts and floods and the likely occurrence of both, i.e. extreme precipitation events after prolonged droughts that may give rise to more extreme phenomena such as deep erosion and landslides. Hertig, Seubert and Jacobeit. (2010) conclude that: "the intra-annual extreme temperature range will decrease in large parts of the Mediterranean area during the 21st century under enhanced greenhouse warming conditions. This is most pronounced for the eastern Mediterranean area. Thus, extreme minimum temperatures in winter are found to increase in the range of up to about 0.25 °C over the Iberian Peninsula and up to 1 °C in the eastern Mediterranean area. Extreme maximum temperatures in summer show a slight negative trend over the Iberian Peninsula, increases of up to 0.25 °C in the south-eastern Mediterranean area, and the maximum increase of about 0.5 °C mainly in the central-northern Mediterranean area."

Besides projections about the mean values of temperature and precipitation as well as their extreme occurrences, other climate change phenomena may be proved of significant importance for the Mediterranean region. It is hypothesized that around much of the Mediterranean basin, sea levels could rise by close to 1 m by 2100. As a consequence, some lowlying coastal areas would be lost through flooding or erosion, while rivers and coastal aquifers would become more salty (Karas, 1997). The worst affected areas will be the Nile Delta (Egypt), Venice (Italy) and Thessaloniki (Greece) where local subsidence means that sea levels could rise by at least one-and a-half times as much as elsewhere.

The Regional Climate Change Index (RCCI) is based on temperature and precipitation mean changes and changes in their interannual variability. Taking into account the aforementioned evidence and projections, it does not come as a surprise that the Mediterranean region emerges as the primary hotspot among the other regions of the globe, having the highest RCCI, indicating a comparatively more receptive region to climate change. Thus, the identification of the Mediterranean region as one of the most prominent hotspots in future climate change projections by Giorgi (2006) is fully justifiable (Figure 3).

2. CLIMATE CHANGE EFFECTS ON MEDITERRANEAN AGRICULTURE

The observed and projected climate change in the Mediterranean region as presented in this work, points to increased temperature, decreased precipitation and expected sea level rise. Iglesias *et al*. (2007) reviewed, among others, the main risks to agricultural production imposed by climate change in Europe and concluded that these risks results from changes in the following factors:

1. water resources and irrigation requirements;
2. soil fertility, salinity and erosion;
3. crop growth conditions, crop productivity and crop distribution;
4. land use;
5. optimal conditions for livestock production;
6. agricultural pests and diseases; and
7. increased expenditure on emergency and remediation actions.

2.1 Water resources and irrigation requirements

Water resources and irrigation requirements will be affected by two climate change processes. First, the simultaneous changes in annual totals of precipitation and of average air temperatures will affect hydrological regimes with an immediate impact on the use and distribution of water within agricultural uses. Second, the seasonality of precipitation and interannual variability may affect crop yields, crop quality and even crop choice. Taking account of past and present water demand, on average, the rate of increase in water demand is around 50 m^3/ha/year in Europe. However, in some cases (Italy, Greece, Maghreb, central Spain, southern France and Germany) water demand is more than 150–200 m^3/ha/year (Lavalle *et al.,* 2009). In the Mediterranean parts of Europe, the declining water balance has been documented over the past 32 years. Taking into account that demand for irrigation water in southern Europe and the Mediterranean area is already very high, under drier conditions more water will be required per unit area, and peak irrigation demands are expected to rise owing to droughts and high temperatures putting crops under severe stress. Decreased availability of water may lead to insufficient water being available for irrigation, resulting in crops suffering moisture stress. At the same time, severely dry conditions will alter the physical properties of soils, and especially soil structure, adding stress to the already strained plants.

North Africa accounts for more than 41 percent (about 6 million hectares) of total irrigated lands in Africa. The Northern region represents more than half of the agricultural water withdrawal of the continent (NIC, 2009). Egypt is a clear example where hydro-intensive crops contribute to the country’s agricultural exports and create income for smallholders. A changing climate, together with the expansion of cultivated areas in the country, will imply additional stress on water resources and will bring negative effects on agriculture and its economy. Tunisia is also experiencing persistent droughts. Rainfed agriculture represents 90 percent of the country's agricultural area, exposing this sector to climate variability. Cereals are important for Tunisia primarily (97 percent) cultivated under rainfed conditions. In the late 1990s, water reserves did not satisfy the water needs of both Tunisia and Morocco, which caused several irrigation-dependent agricultural systems to cease production.

For Cyprus, a 15 percent decrease in precipitation from 540 mm to 460 mm (15 percent) could lead to a 41 percent decrease in water resources (Bruggeman *et al.,* 2012) with serious impacts on agriculture, taking into account that agriculture in Cyprus uses more than half of the available freshwater. In Israel, the 2010 Climate Change Report of the Ministry of Environmental Protection pointed out that potential impacts of climate change on water may include an increase in the frequency and severity of floods, which may cause major damage to property and people, a 25 percent reduction in water availability for 2070–2099 in comparison with 1961–1990, a reduction in groundwater recharge, a loss of an estimated 16 million m^3 of water for each kilometre along the coastal plain as a result of a potential rise in sea level of 50 cm and changes in the salinity level of the Sea of Galilee, the major freshwater supplier of the country (Shachar, 2011). In Turkey, the likely consequences of climate change on surface waters were examined using a water budget model for the Gediz and Büyük Menderes Basins along the Aegean coast. As the European Environment Agency (EEA) indicates in its Country Assessment Reports, the results showed that by 2050, water runoff will be reduced by 35–48 percent, potential evaporation will increase by 15–17 percent, crop water demand will increase by 19–23 percent and surface waters will be reduced by about 35 percent.

2.2 Soil fertility, salinity and erosion

Owing to the fact that soil degradation and the consequent risk of desertification are major problems especially in the Mediterranean area, and are issues impacting land use far beyond agriculture and forestry, section 3 of this report is solely devoted to an examination of climate change impacts on soil erosion and desertification. Iglesias *et al.* (2007) detail a range of soil conservation problems including high erosion rates (and erosion-derived agro-chemical pollution of waterways), declines in soil organic matter and vulnerability of soil organic carbon pools, which are linked to site factors and changing land management practices but will be exacerbated by climate change and the increasing incidence of extreme weather events.

2.3 Crop growth, productivity and distribution

Crop growth conditions and crop productivity are interrelated issues. Basically crop growth is affected by climate conditions, CO_2 concentration and technology. Concerning climate conditions, the basic variables are precipitation and air temperature that control soil moisture and water availability to plants and affect evapotranspiration. In addition, other variables such as wind velocity, the occurrence of early frosts or ice and the time occurrence of extreme phenomena are important as they can exercise significant stress on plants and put production at risk. Ewert *et al.* (2005) argue that, for all the above factors, technology is so important that it can outweigh all the negative impacts brought by climate change. Alcamo *et al.* (2007) reviewed studies concerning the impacts of climate change on crop production in Europe and concluded that in Southern Europe, general decreases in yield (e.g. legumes –30 to +5 percent; sunflower –12 to +3 percent and tuber crops –14 to +7 percent by 2050) and increases in water demand (e.g. for maize +2 to +4 percent and potato +6 to +10 percent by 2050) are expected for spring-sown crops (Giannakopoulos *et al*., 2005; Audsley *et al.,* 2006).

The impacts on autumn-sown crops are more geographically variable; yield is expected to decrease strongly in most southern areas, and increase in northern or cooler areas (e.g. wheat: +3 to +4 percent by 2020, –8 to +22 percent by 2050, –15 to +32 percent by 2080) (Santos, Forbes and Moita, 2002; Giannakopoulos *et al*., 2005; Audsley *et al.,* 2006; Olesen *et al.,* 2007). Alcamo *et al.* (2007) also argue that in the European Mediterranean region, increases in the frequency of extreme climate events during specific crop development stages (e.g. heat stress during flowering period, rainy days during sowing time), together with higher rainfall intensity and longer dry spells, are likely to reduce the yield of summer crops (e.g. sunflower).

Jones and Thornton (2003) examined the potential changes in maize production, the most important crop for smallholders. Climate change in Africa and Latin America, including Morocco, modelled using the HadCM2 simulated changes in temperature and precipitation for the period 2040–2069 (“2055”). These climate projections were used by the CERES-Maize crop model to simulate the growth, development and yield of maize crops. For Morocco in 2055, the model predicted a substantial increase in maize crop yield owing to the effects of climate change, from a baseline value of 317 kg/ha to a value of 550 kg/ha, an approximately 175 percent increase. The positive effects of increased atmospheric CO_2 concentrations may be the dominant influence on future maize crop yield in Morocco.

In Israel, recent studies suggest that over the period up to 2020 climate change could be beneficial to agriculture, as a result of Israel’s Israel to supply international markets earlier in the season (Fleischer, Lichtman and Mendelsohn, 2008), although this result is disputable in some models (Kan, Rapaport-Rom and Shechter, 2007). Bruggeman *et al.* (2012) estimated climate change projections for Cyprus from an ensemble of six Regional Climate Models, under the IPCC-SRES medium A1B emission scenario, which indicated an increase in temperatures and highly variable but slightly lower precipitation amounts for the 2013/14≠2019/20 seasons. They simulated two climate scenarios, one worst-case scenario, represented by the seven dry years from the 1980/81–2008/09 record and a medium scenario made up of three dry years, two average years and two wet years, each with the highest evapotranspiration rates within their class. For both scenarios, irrigation water demand was reduced to 129X106 m^3/year, as recommended by recent national water management policies, which was achieved by reducing all irrigated crop areas of the 2010 Cypriot Agricultural Payments Organization (CAPO) crop areas by 25 percent. The computed annual national crop production for 2013/14-2019/2020 was reduced by 41 percent, on average, under scenario 1 and by 43 percent under scenario 2, relative to 1980/81–2008/09. The average loss of irrigated production was 193X103 tonnes/year under scenario 1 and 216X103 tonnes/year under scenario 2, whereas the average rainfed production loss was 132X103 tonnes/year (scenario 1) and 125X103 tonnes/year (scenario 2).

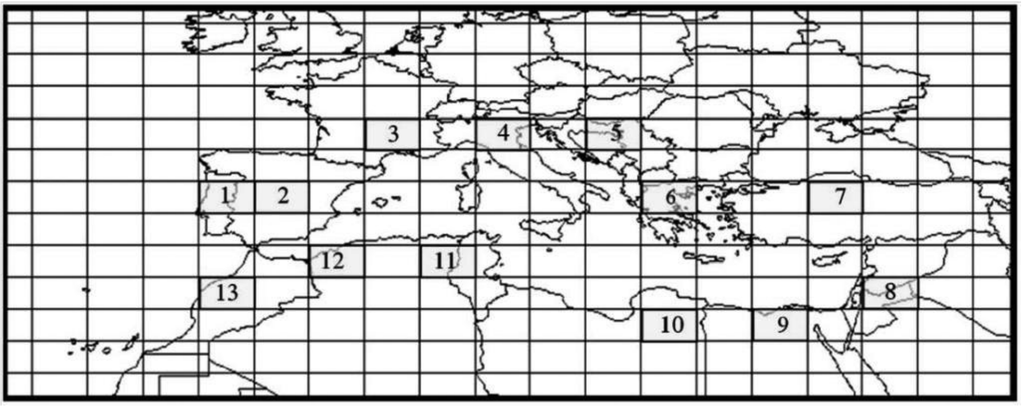

Figure 4. Grid cells of HadCM3 selected for the impact assessment on agriculture by the Giannakopoulos *et al.* (2009) study
Source: Panel 2 in Giannakopoulos *et al.* (2009).

Giannakopoulos *et al.* (2009) provide the most comprehensive, comparative study of climatic changes over all countries in the Mediterranean basin in 2031–2060, with a 2 °C global warming scenario, investigated with the HadCM3 global circulation model. They examined precipitation and surface temperature changes through mean and extreme values analysis, under the A2 and B2 emission scenarios. Figure 4 shows the 13 grid cells (called hotspots) of the HadCM3 that were selected to provide a homogenous cover of Mediterranean basin and where changes in precipitation and temperature patterns are expected to be substantial, according to HadCM3 model simulations. Over the land areas, the warming is larger than the global average. The rate of warming is found to be around 2 °C in spring and winter, and reached 4 °C in summer. An additional month of summer days is expected, along with 2–4 weeks of tropical nights. Increase in heatwave days and decrease in frost nights are expected to be a month inland. In the northern part of the basin, the widespread drop in summer rainfall is partially compensated by a winter precipitation increase. One to three weeks of additional dry days lead to a dry season lengthened by a week and shifted towards spring in the south of France and inland Algeria, and autumn elsewhere. In central Mediterranean area, droughts are extended by a month, starting a week earlier and ending three weeks later.

In Giannakopoulos *et al.* (2009), crop yields are assessed through the CROPSYST model and HadCM3 data including minimum and maximum temperatures, rainfall and global radiation. CROPSYST simulates crop productivity under selected present and future climate scenarios under a multiyear, multicrop, daily time-step crop growth simulation model, which simulates the soil water budget, the soil–plant nitrogen budget, crop canopy and root growth, crop phenology, dry matter production, yield, residue production and decomposition, and erosion. It is important to note that this model allows the user to specify management parameters such as sowing date, cultivar genetic coefficients, soil profile properties, fertilizer and irrigation management, tillage and atmospheric CO_2 concentration in order to simulate resilience-adaptation and mitigation measures. CROPSYST simulates changes in mean climate conditions and not the occurrence of extreme events. Also, it is important to note that CROPSYST, as many models under this family of simulation models, are first calibrated to fit as much as possible the data reported on the FAOSTAT database. Giannakopoulos *et al.* (2009) calculated, for each hotspot and crop type, the annual values of development stages and yields for the two time-slices (1961–1990 and 2031–2060). For the present climate, the simulation runs were performed setting the atmospheric concentration of CO_2 at 350 ppm and for the future climate scenarios were performed with increasing CO_2 (470 ppm under scenario B2 and 520 ppm under scenario A2). In this study, the CROPSYST model was rerun introducing adaptation management strategies (e.g. changes in sowing dates, cultivar, etc.) that may reduce the negative impact of climate change or enhance positive impacts. In all simulations under this study, the C4 summer crops and tuber crops were considered as "irrigated crops", whereas the rest of the crops were considered as "rainfed crops". Nitrogen was considered not limiting for all the crops.

Figure 5 from Giannakopoulos *et al.* (2009) shows that the impacts of these climatic changes on crops whose growing cycle occurs mostly in autumn and winter showed no changes or even an increase in yield. In contrast, summer crops showed a remarkable decrease in yield. This different pattern is attributed to a lengthier drought period during summer and to an increased rainfall in winter and autumn. The authors draw two very significant conclusions, one concerning climate change impacts without the presence of any adaptation practice and one under adaptation practice (adaptation on-off). Giannakopoulos *et al.* (2009) examine five categories of plants: C4 summer crops – plants that produce a four carbon molecule and for which increased CO_2 has little effect on the rate at which photosynthesis occurs, such as sorghum; legumes – plants capable of fixing atmospheric nitrogen, such as beans, peas and alfalfa; C3 summer crops – plants that produce a three carbon molecule, are very responsive to CO_2 levels and photosynthesize at a faster rate under increased CO_2 concentrations, such as rice, wheat and soybeans; tuber crops such as potatoes; and cereals (the interested reader is refereed to Gillis, 1993 for a review of the evolution of C3 and C4 plants). Without adaptation they found that "the effect of climate change on agriculture is likely to be more severe in the southern Mediterranean areas than in the northern temperate areas. In the warmer southern Mediterranean, increases in CO_2 help reduce the loss in yield arising from a warmer and drier climate, but are not able to completely recover the losses. In the cooler north-eastern Mediterranean, CO_2 increases associated with climate change result in little net effect on most crops, provided that the increase in water demands, especially for irrigated crops, can be met".

Iglesias *et al*. (2011a) selected nine sites to represent the major agroclimatic regions in Europe. At each site, they simulated crop response to climate and management by using the DSSAT crop models of the International Consortium for Agricultural Systems Applications (ICASA) for wheat, maize and soybeans. Simulated wheat responses to climate are representative of possible responses of winter cereals in all regions and winter and spring cereals in the Mediterranean regions. The authors selected these crops because they are representative of approximately two-thirds of arable land in most regions of Europe and have been used on numerous occasions to represent world food production. As concerns crop productivity, the authors conclude that "crop productivity increases in northern Europe and decreases in southern Europe".

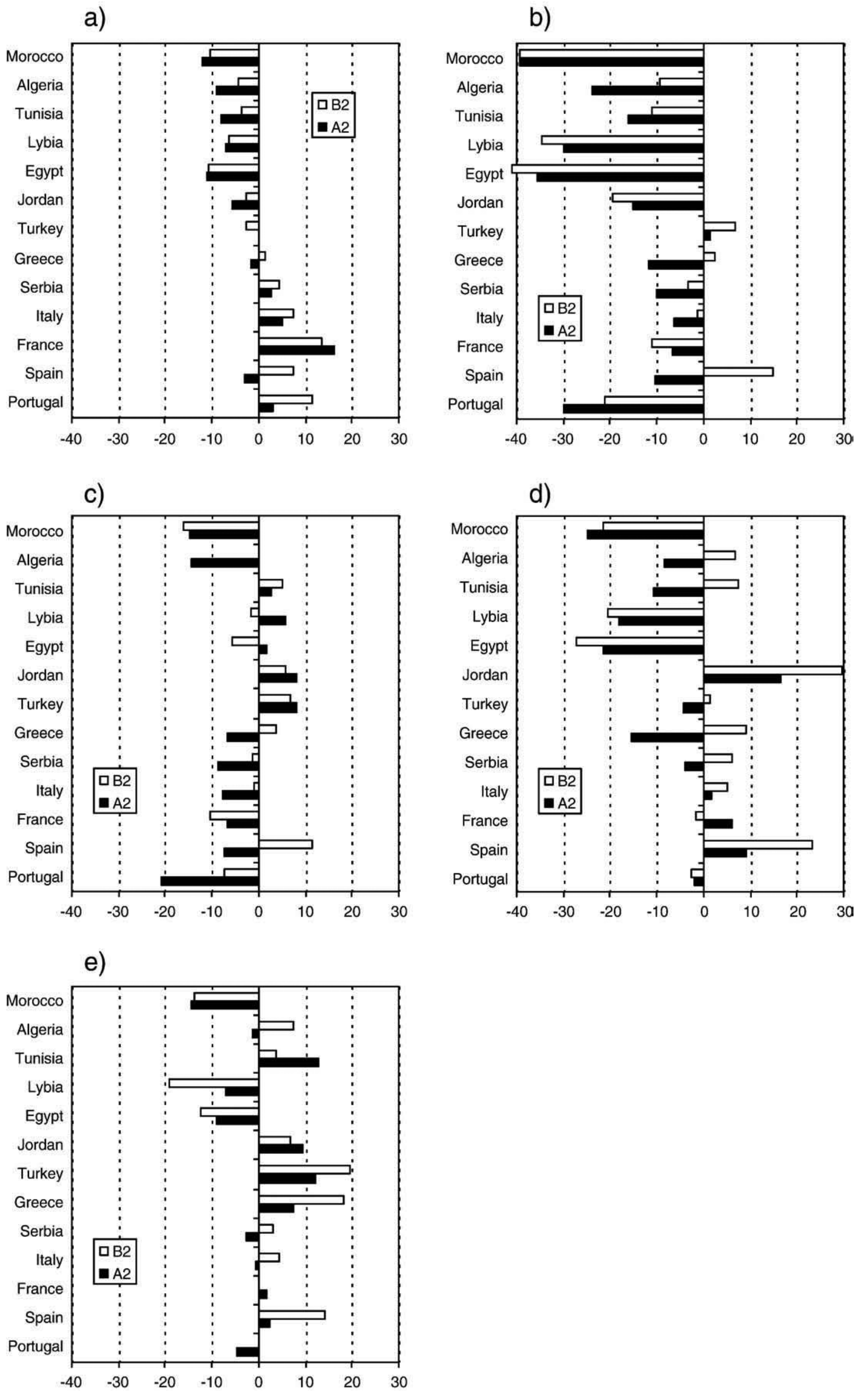

Figure 5. Impact of climate change on crop productivity for: (a) C4 summer crop, (b) legumes, (c) C3 summer crop, (d) tuber crops, (e) cereals

The changes in the figure are expressed as percentage differences between future (both A2 and B2 scenarios) and present yields.
Source: Figure 9 in Giannakopoulos *et al.* (2009).

Based on observations, experiments and model analyses carried out by the National Institute for Agricultural Research in Morocco, several potential changes to agricultural growing seasons in Morocco were outlined in Morocco's First National Communication to the United Nations Framework Convention on Climate Change (Kingdom of Morocco, 2001). Likely changes in the twenty-first century include a reduction in the growth period of regional crops, a reduction in the duration of crop cycles, and an increase in the risk of dry periods during the course of crop cycles. Hegazy *et al.* (2008) investigated the influence of increased air temperatures associated with future climate change on the spatial and temporal distribution of four crops in Egypt through 2100. Analysis focused on cotton, wheat, rice and maize. Air temperature patterns in Egypt for 2025, 2050, 2075 and 2100 were simulated using a database of information compiled from multiple GCMs run under the B2 emissions scenario. Crop simulations were based on the optimum air temperatures for maximum growth of cotton, wheat, rice and maize throughout the agricultural season, which are 23.0 °C, 16.8 °C, 25.8 °C, and 26.0 °C, respectively. The study showed that a shift in crop sowing dates to earlier in the season, to prevent crop losses due to excessively warm growing conditions, is very likely. Compared with the reference sowing year of 2005, the model study predicted future sowing dates will shift one to eight weeks earlier, depending on the crop type, region and year. The exception is rice sowing in Upper Egypt, which is expected to shift one week later in 2025 and remain unchanged in 2050 and 2075. Wheat is the most sensitive of the four analysed crops to changing temperatures, and the models estimate that by 2100 air temperatures will be so high that growing wheat in Egypt will be impossible.

2.4 Land-use impacts

Crop yields under climate change are determined by changing environmental growth conditions (precipitation, air temperature, extreme events and elevated CO_2 concentrations) as these are projected in each of the four basic SRES scenarios. In addition, crop production is also determined by global demand and supply factors and the available technology. One issue still to be resolved concerns the effects of changing crop yields on land-use patterns. In other words, how one can model the implications of changes in crop productivity induced by climate change on land-use allocation. As an example of the limitations and uncertainty of the results of such models, one attempt to project changing land-use patterns under climate change was reviewed. This model does not explicitly address Mediterranean agriculture but includes the Mediterranean region as part of a wider European study.

Rounsevell *et al.* (2005) employed a supply and demand model for agriculture for 15 European Union countries plus Norway and Switzerland under four market scenarios (A1FI, A2, B1, B2). This resulted in an assessment of the total area requirement (quantity) of agricultural land use (ha) at the European scale, as a function of changes in relevant drivers including: world supply and demand trends, market intervention through agricultural policy, rural development policy, environmental policy, EU enlargement, land resource competition (e.g. urbanization, recreation, bioenergy crops), the role of the World Trade Organisation (WTO) and climate change through its effect on crop productivity. The quantities of agricultural areas were then spatially distributed (disaggregated) across the European territory using spatial allocation rules. For the A1FI scenario, a globally and economically orientated scenario, the authors assumed all agricultural production to be centred on optimal locations. This generates a pattern of land-use change that is spatially uneven and which favours good production areas over poorer quality regions. Thus, allocation of the decline in land areas estimated at the European scale is assumed to be first taken up by the less favoured areas of the EU (LFAs) and any remaining declines are then accounted for non-LFA areas. For the A2 scenario, all land area changes were distributed equally between the European regions to take account of a certain degree of regional protectionism for reasons of national food security. For the B1 scenario, which is an environmentally and equity-orientated scenario, the authors allowed for oversupply for benefiting and maintaining farmers' incomes and rural communities. Thus, for B1 the authors allowed no decline in grassland but assumed cropland production to be located on optimal locations, as for the A1FI scenario. For the B2 scenario the authors assumed a B1 situation with the addition of no declines in cropland. The authors assumed that the oversupply associated with this scenario would be offset by policy measures that seek to reduce productivity by encouraging extensification and organic production.

Figure 6 shows the decline in cropland and grassland under the four scenarios after Rounsevell *et al.* (2005). Cropland areas decline substantially by 2080 for the A1FI and A2 scenarios. Cropland decline for the B1 scenario is less severe and for the B2 scenario is the smallest because, although cropland areas are assumed constant, some cropland area for food production is replaced by bioenergy production. Declines in the grassland areas for A1FI and A2 are even higher. Changes in grassland areas for the B1scenario are the least severe because of assumed protection policies, while changes for the B2 scenario reflect, as in the case of cropland, a switch from food to bioenergy production.

Rounsevell *et al.* (2005) provide a breakdown of the scenario results of Figure 6, by country for cropland and grassland in 2080. Table 1 shows the estimated regionalized decline in cropland for selective Mediterranean European countries. For the A1FI scenario, the authors conclude that countries in the south of Europe, such as Spain (–74 percent), Portugal (–73 percent) and Greece (–68 percent), experience very large declines in agricultural areas that are much greater than the European-wide changes presented in Figure 6. As they argue, "this reflects the potential for regional disparities within a globally

Table 1: Share of cropland out of total land for the baseline and the four SRES scenarios in Mediterranean countries and Europe

	Baseline (%)	A1FI in 2080 (%)	A2 in 2080 (%)	B1 in 2080 (%)	B2 in 2080 (%)
Portugal	26.98	7.24 (–73)	14.22 (–47)	12.49 (–54)	17.23 (–36)
Spain	33.17	8.78 (–74)	17.54 (–47)	17.23 (–48)	23.69 (–29)
France	45.87	26.70 (–42)	24.71 (–46)	32.91 (–28)	32.52 (–29)
Italy	39.53	20.13 (–49)	20.87 (–47)	25.57 (–35)	27.21 (–21)
Greece	25.66	8.18 (–68)	13.50 (–47)	13.96 (–46)	17.30 (–33)
Europe 17	23.02	12.27 (–47)	12.66 (–45)	16.01 (–30)	16.65 (–28)

Note: Numbers in parentheses are percentage decline from baseline.
Source: Selective data from Table 8 in Rounsevell *et al.* (2005).

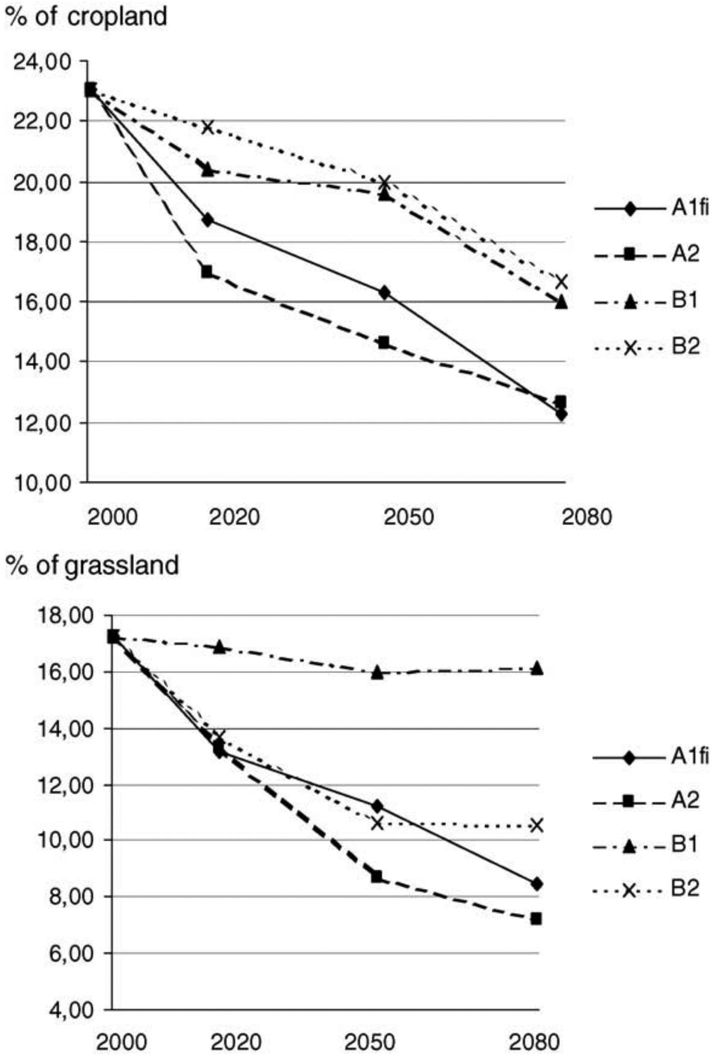

Figure 6. Changes in cropland and grassland under the four climate change scenarios as percentage of total European area

Source: Figures 2 and 3 in Rounsevell *et al.* (2005).

orientated scenario". Of course, such a result opens a discussion concerning the future of this potentially surplus agricultural land. And, while it may be argued that agricultural land will be converted to recreational areas (including golf-courses and other sport utilities, fields for horse riding and camp sites), this may be true only for central and northern Europe. In the Mediterranean region, with such a projected stress on water resources, this land-use change is rather unlikely, and there may be a change to forest land use. On the other hand, the scenarios presented by Rounsevell *et al.* (2005) have assumed that bioenergy production will take up a certain proportion of the surplus agricultural land but again this will put more stress on the already limited water resources. Finally, Rounsevell *et al.* (2005) suggest that potential structural changes in the farming sector such as increasing farm sizes might represent an appropriate adaptation strategy to land-use change pressures.

2.5 Livestock production

Concerning livestock production, Iglesias *et al.* (2007) argue that "a warmer and drier climate may reduce forage production leading to changes in optimal farming systems and a loss of rural income in areas dependent on grazing agriculture". As Olesen (undated) in the foresight section of the Standing Committee on Agricultural Research (EU) web site reports: "higher temperatures result in greater water consumption and more frequent heat stress, which causes declines in physical activities, including eating and grazing. Livestock production may therefore be negatively affected in the warm months of the currently warm regions of Europe". Climate change impacts will probably be minor for intensive livestock systems (e.g. confined dairy, poultry and pig systems) because climate is controlled to some degree.

2.6 Agricultural pests and diseases

Climate change and especially higher air temperatures will create conditions suitable for the invasion of weeds, pests and diseases adapted to warmer climatic conditions. The speed at which such invasive species will occur depends on the importance of climatic change, the dispersal rate of the species and on measures taken to combat non-indigenous species (Anderson *et al.*, 2004). The dispersal rate of pests and diseases is most often so high that the geographical extent is determined by the range of climatic suitability (Baker *et al.*, 2000). The Colorado beetle, the European cornborer, the Mediterranean fruit fly and karnal bunt are examples of pests and diseases that are expected to have a considerable northward expansion in Europe under climatic warming. Alcamo *et al.* (2007) review the relevant literature and argue that: "increasing temperatures may also increase the risk of livestock diseases by (i) supporting the dispersal of insects, e.g., *Culicoides imicola*, that are main vectors of several arboviruses, e.g., bluetongue (BT) and African horse sickness (AHS); (ii) enhancing the survival of viruses from one year to the next; (iii) improving conditions for new insect vectors that are now limited by colder temperatures".

2.7 Economy-wide effects

A shift in the location of optimal conditions for specific crop or livestock production systems may lead to a loss of rural income and soil deterioration in the areas where those modes of production can no longer be maintained. Such losses of established farming practices may lead, among others, to land abandonment and increased risk of desertification with a high probability of occurrence during the twenty-first century (Iglesias *et al.*, 2007). In addition, rising sea levels may also lead to significant land-use changes. It is argued that an indirect effect on agriculture may occur if rising sea levels make population centres uninhabitable. The displaced populations will need to be housed and at least some of the housing is likely to be built on agricultural land. It is estimated that about 72 percent of the dwellers in African cities live in slums that have particularly poor drainage facilities and are quite often prone to rising sea levels, which could affect many of the regions' coastal cities, particularly in low-lying areas in Egypt, Tunisia and Morocco. As an example, in Egypt, there is increasing concern about how rises in sea levels might impact the Nile Delta. It has been estimated that a sea level rise of 50 cm in the Delta could displace over 2 million people, flood 1 800 km^2 of cropland, and generate some USD35 billion in damage in terms of loss of land, property and infrastructure (OSS/UNEP, 2010). Finally, we should be aware that climate change impacts on agricultural activity will have economy-wide impacts triggered by changes in crop productivity. Unfortunately, research in this area is rather limited for the Mediterranean region and we can rely on published work that includes the European Mediterranean part of the region. Iglesias *et al.* (2011a) use a Computable General Equilibrium (CGE) model based on the Global Trade Analysis Project (GTAP) CGE system for seven European regions, four sectors (crops, other agrarian goods, manufacturing and services) and four factors (land, labour, capital and energy). Of the seven European regions, two represent European Mediterranean areas, namely the Mediterranean North (France and Portugal) and the Mediterranean South (Cyprus, Greece, Italy, Malta and Spain). Crop productivities are estimated under the A2 and B2 scenarios using the DSSAT model, NOAA climate data and EUROSTAT crop distribution and production data. Technological change is modelled with an improvement of 1 percent per year in 2001 and an exponential slowdown in productivity per decade. None of the simulations considered any restrictions on water use for irrigation or application of nitrogen fertilizers. The external shock to the system comes from land productivity changes as a result of climate changes. This will have an effect on input prices that may trigger price changes in agricultural goods that are spread to the other sectors of the economy through various channels such as changes in wages.

Figure 7 shows these changes for the gross domestic product (GDP), agricultural trade and the price of labour. The effects of climate change on GDP depend basically on two factors: first, negative or positive productivity changes owing to modified climate conditions; second, the importance of the agricultural economy in terms of its share in the overall economy. Thus, in areas with significant productivity losses such as the Mediterranean south, and with the agricultural sector still playing a significant role in the overall economy, GDP changes are negative and significant especially under the A2 scenario (upper part of Figure 7). Of course, the effects on GDP are much lower (positive or negative) than the respective changes in land productivity. As the authors note, changes in agriculture imports and exports are wider than the changes in GDP. The agricultural trade balance would increase because of the lower crop prices induced by land productivity gains. These lower prices assign a competitiveness gain for European crops in world agriculture markets. However, in the Mediterranean regions, the crop supply changes are negative, which result in higher prices and no gains for the agricultural trade balance (middle part of Figure 7). Especially in the Mediterranean south, the agricultural trade balance under the A2 scenario may deteriorate by almost 10 to 15 percent depending on the climate model (HadCM or ECHAM). The price of labour moves in the same direction as land productivity (lower part of Figure 7).

3. CLIMATE CHANGE AND SOIL DESERTIFICATION IN THE MEDITERRANEAN AREA

The issue of land degradation and desertification in the Mediterranean region was briefly presented in section 2.2 above, but, owing to its significant importance, this section of the paper provides a more comprehensive review of the relevant literature. The issue

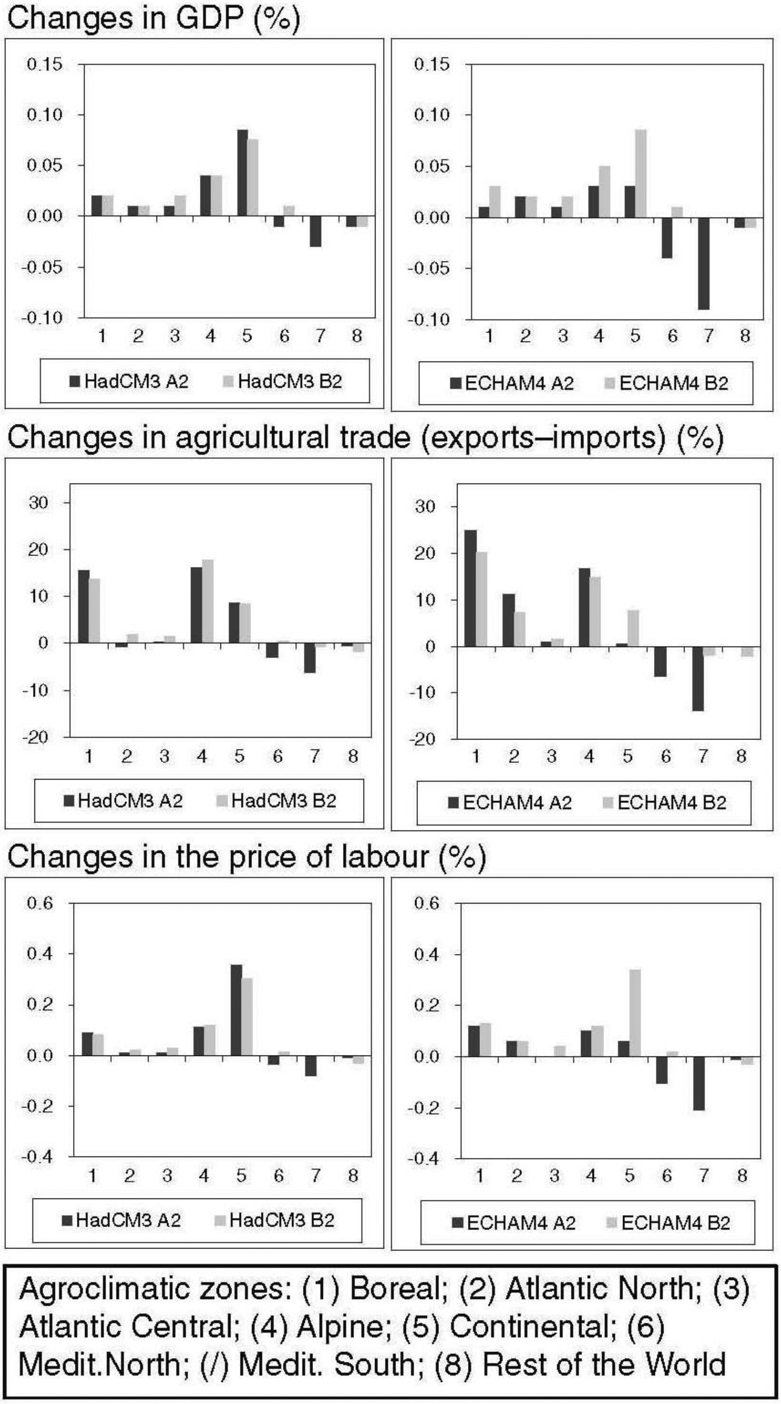

Figure 7. Economy-wide implications of climate induced changes in land productivity
Source: Figure 6 in Iglesias *et al.* (2011a).

of desertification is not new but only very recently have serious efforts been made to identify and understand the driving forces and processes as well as the implications of land degradation. The term "desertification" refers to land degradation in arid, semi-arid and dry subhumid areas resulting from climate variations and human activity. The most significant aspect of land degradation is the decline in soil fertility and soil structure and the consequent reduction of the land's carrying capacity for plants, animals and humans. This leads to widespread poverty, overexploitation and ultimately destruction and abandonment of land (Wrachien, Ragab and Giordano, 2006). Soil degradation is a paramount concept encompassing a range of processes such as, erosion caused by water, wind and tillage, decline in organic carbon content, compaction, salinization and sodification, contamination by heavy metals or pesticides, the excess presence of nitrates and phosphates, and decline in biodiversity.

Wrachien, Ragab and Giordano (2006) identified three major driving forces behind desertification in the Mediterranean region: first, a change in agriculture from extensive systems based on grazing and dryland wheat to intensive agriculture based on tree crops, horticulture and irrigation; second, social changes accompanied by an improvement in the standard of living and migration from the countryside to the city or overseas; third, the growth of tourism and the littoralization of the Mediterranean economy. Chisci (1993) adds that the move of agricultural systems away from extensive types of livestock-grazing towards specialized-mechanized hill farming has added to the modification of morpho-structural and infrastructural features of the landscape: soil disturbance by ploughing up-and-down contour lines, removal of vegetative soil cover and/or hedgerows, increased field size and abandonment of terraces, late sowing of winter cereals, overstocking, poor crop management and inappropriate use of heavy machinery, in agricultural and forestry practices or during construction works. In addition, land abandonment owing to migration or economic marginalization of previously cultivated fields and farms has altered the landscape and has increased the risk of forest and pasture fire. Land erosion as part of the wider land degradation processes has important on-site and off-site effects. Soil erosion is responsible for on-site loss of organic matter, soil structure degradation, soil surface compaction, reduction of water penetration, supply reduction to the water table, surface erosion, nutrient removal, increase of coarse elements, rill and gully generation, plant uprooting and reduction of soil productivity. Off-site effects are equally if not more important than on-site effects. Eroded soils contribute to higher runoff rates and sedimentation, with a risk of floods and the consequent damage to infrastructures. Reduced water retention capacity as a result of lower infiltration rates is associated with many issues, especially water management through aquifers.

Panagos *et al.* (2012) have modelled soil erodibility in Europe by utilizing the K-factor in the commonly used soil erosion model USLE (Universal Soil Loss Equation). The K-factor is related to crucial soil factors triggering erosion (organic matter content, soil texture, soil structure, permeability). Panagos *et al.* (2012) calculated soil erodibility using measured soil data, collected during the 2009 Land Use and Cover Area frame Survey (LUCAS) soil survey campaign across the member states of the European Union. Figure 8 shows the soil erodibility in Europe where it is evident that southern Europe and the

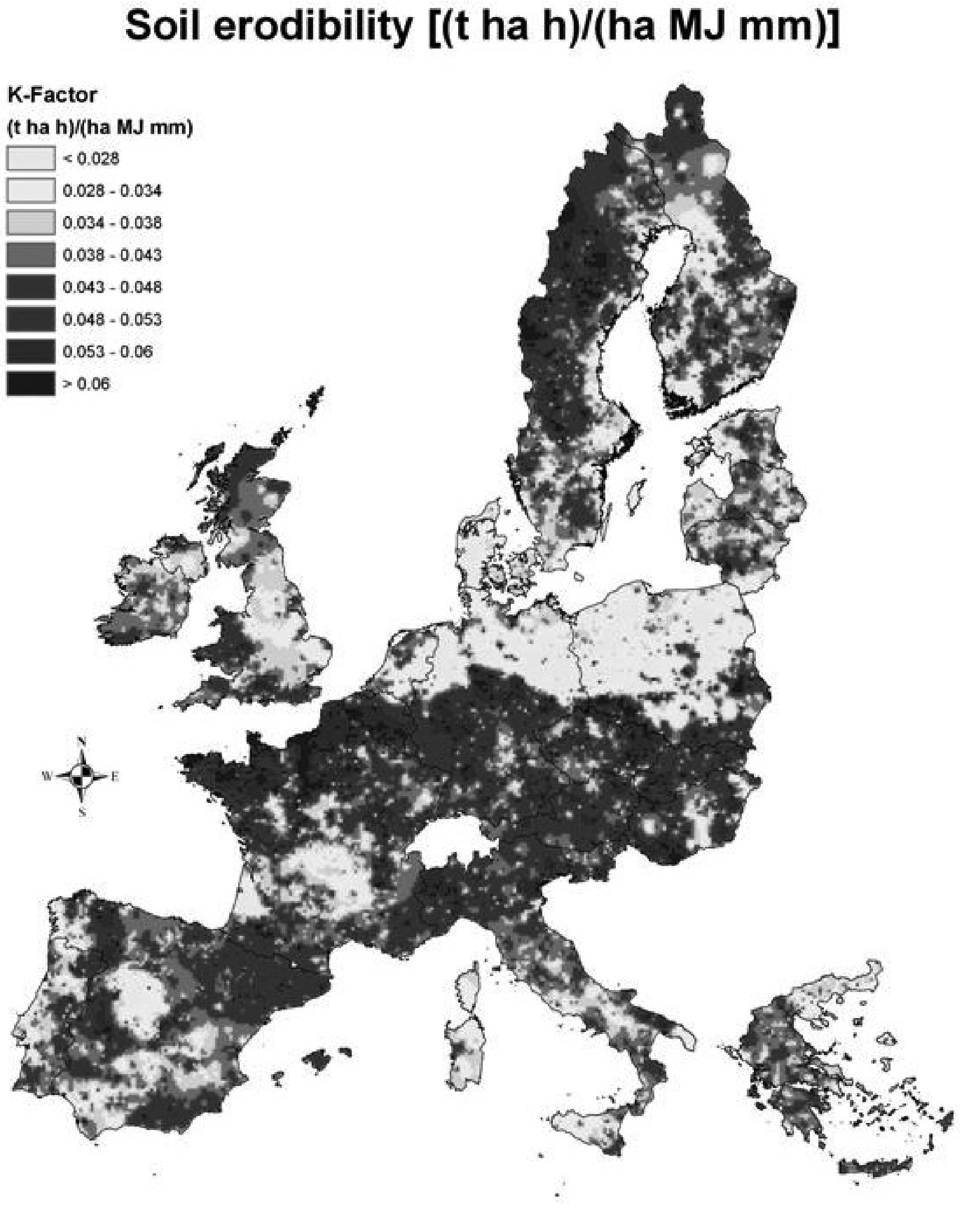

Figure 8. Soil erodibility in Europe
Source: Panagos *et al.* (2012). Source of map: http://eusoils.jrc.ec.europa.eu/library/themes/erosion/Erodibility/, last accessed 22 February 2012.

Mediterranean region suffer from high erosion. It was recognized early on that soil erosion is of considerable importance for southern Europe and the Mediterranean, and for this reason the European Commission launched a first attempt to map natural resources and soil erosion risks in Mediterranean Europe (CORINE, 1992). Since then, data availability has improved and more research activities such as the Pan-European Soil Erosion Risk

Assessment Project (PESERA) were supported. The Commission of the EU reported that: "An estimated 115 million hectares or 12 percent of Europe's total land area are subject to water erosion, and 42 million hectares are affected by wind erosion and that an estimated 45 percent of European soils have low organic matter content, principally in southern Europe but also in areas of France, the United Kingdom and Germany" (European Commission, 2006a). The Mediterranean region is particularly prone to erosion as it is subject to long dry periods, followed by heavy bursts of erosive rain, falling on fragile soils on steep slopes. It is estimated that, at present, water erosion in the Mediterranean region could result in the loss of 20/40 tonnes/ha of soil after a single cloudburst, and in extreme cases the soil loss could be over 100 tonnes/ha. Soil erosion and the risk to desertification in southern Europe and the Mediterranean are closely related to the forecasted increase of forest and wilderness fires and the consequent canopy removal, especially on high slope areas.

According to the United Nations Convention to Combat Desertification (UNCCD), the North Africa subregion represents the entire range of the aridity index. The major issues of concern in the subregion are rainfall variability, recurrent droughts, and possible impacts of climate change. All land-use categories in North Africa are subject to land degradation processes, through more than three decades, owing to several pressures including: rapid population growth, climatic stresses, human mismanagement practices, and inappropriate agricultural policies (UNCCD). Land degradation processes are varied and diversified under both rainfed and irrigated conditions, range and forestlands and conducive to serious productivity losses, reduction in return from capital investment, lower income of rural households, spread of poverty and increased rural to urban migration. A combination of some of these threats will increase under climate change and can ultimately lead areas of the Mediterranean to desertification, i.e. land degradation in arid, semi-arid and dry subhumid areas resulting from climate variations and human activity (Wrachien, Ragab and Giordano, 2006). Global climate change could have significant impacts on soil erosion, but these impacts have received little research attention since they involve complex interactions between multiple factors governing erosion rates (Kundzewicz *et al.*, 2007). Thus, climate change, with its short- and long-term variation and gradual changes in temperature and precipitation, will apply an additional stress on rates of land degradation through:

- changes in the length of days and/or seasons;
- recurrence of droughts, floods and other extreme climatic events;
- changes in temperature and precipitation, which in turn reduce vegetation cover, water resource availability and soil quality; and
- changes in land-use practices, such as conversion of lands, pollution and depletion of soil nutrients. (UNCCD website accessed at: http://www.unccd.int).

Research suggests that climate change-induced land degradation will vary geographically. The underlying adaptive capacity of both the ecosystem and communities will determine the extent and direction of impacts. Regions that are already constrained by issues such as land quality, poverty, technology constraints and other socio-economic constraints are likely to be more adversely affected. Concern is particularly focused on regions where increased rates of land degradation as a result of climate change are likely to decrease livelihood opportunities and worsen rural poverty. Nunes *et al.* (2009) argue that "the impacts of climate change on storm runoff and erosion in Mediterranean watersheds are difficult to assess due to the expected increase in storm frequency coupled with a decrease in total rainfall and soil moisture, added to positive or negative changes to different types of vegetation cover". Nunes *et al.* (2009) analysed the sensitivity of runoff and erosion to incremental degrees of change (from −20 to + 20 percent) to storm rainfall, pre-storm soil moisture and vegetation cover, in two Mediterranean watersheds. The authors underline the high sensitivity of storm runoff and peak runoff rates to changes in storm rainfall (2.2 percent per 1 percent change) and to soil water content (−1.2 percent per 1 percent change). However, at a catchment level, their results showed a greater sensitivity than those within-watershed. In addition, the authors conclude that "… decreasing soil moisture levels caused by climate change could be sufficient to offset the impact of greater storm intensity in Mediterranean watersheds".

Finally, it should be acknowledged that soils play an important role in carbon sequestration, and thus processes that destruct soil structure such as erosion and desertification may have serious impacts on this process. Lal (2004) argues that soil erosion and deposition are responsible for losses in the soil organic carbon (SOC). The SOC is preferentially removed by wind- and water-borne sediments through erosional processes. Lal (2004) argues that although some of the SOC-enriched sediments are redistributed over the landscape, others are deposited in depressional sites, and some are carried into the aquatic ecosystems. The carbon emitted into the atmosphere either as CO_2 by mineralization or as CH_4 by methanogenesis may be as high as 0.8 to 1.2 Gt per year globally, while erosion-induced deposition and burial may be responsible for 0.4 to 0.6 Gt per year. Quantification of emission versus burial of carbon is a high priority. However, effective soil erosion control is essential to sustainable use of agricultural soils and improving environment quality.

4. MEDITERRANEAN FORESTS UNDER CLIMATE CHANGE

Saket and Hayder (2010) argue that "climate change is expected to have significant, if not severe, impacts on Mediterranean ecosystems". Forecasted climate change and the occurrence of extreme events in southeast Europe and the Mediterranean region are expected to have significant impacts on forests and forest ecosystems in general. Lindner *et al.* (2008) recount the likely impacts of climate change on Mediterranean forest ecosystems and especially on wood production, non-wood forests products, carbon sequestration and biodiversity. The importance of this issue has mobilized not only the European Union but also FAO and individual governments. In December 2009, the German Federal Ministry for Economic Cooperation and Development approved the regional project "Adapting forest policy conditions to climate change in the Middle East and North Africa (MENA) region" with the aim of improving the political framework conditions for the sustainable management of forest ecosystems in order to preserve forest-related environmental services in the context of climate change in selected countries of the MENA region that have sizable forest areas (Morocco, Algeria, Tunisia, Turkey, Syrian Arab Republic and Lebanon).

Keenan *et al.* (2011) assess the potential future of current forest stands in the Mediterranean basin, where important future climatic changes are expected. CO_2 fertilization through projected increased atmospheric CO_2 concentrations is shown to increase forest productivity in a mechanistic process-based model framework, despite increased drought stress. This increase is up to three times that of the non-CO_2 fertilization scenario by the period 2050–2080. In a niche-based model framework, projections of reduced habitat suitability are drawn for the same period. This highlights the importance of introducing aspects of plant biogeochemistry into current niche-based models for a realistic projection of future species distributions. The authors conclude that the future of current Mediterranean forest stands is highly uncertain and suggest that a new synergy between niche- and process-based models is urgently needed in order to improve our predictive ability.

De Dios *et al.* (2007) reviewed more than 60 studies addressing the effects of global warming on forest ecosystems and drew a long list of possible impacts that can be categorized under three headings: forest health, species migration and displacements, and fire erosion and desertification. Sturrock *et al.* (2011) provided an extensive review of the impact of climate change on forest diseases at a global scale and highlighted the relationships between climate variables and several forest diseases, as well as the processes by which climate, host and pathogen interactions are responding or might respond to climate change. De Dios *et al.* (2007) argued that climate change, by worsening climate conditions in the Mediterranean, will trigger two processes that will impact forest health. First, trees will be weakened by unfavourable environmental conditions in increasingly larger proportion and will become susceptible to pathogens. Thus, many trees will die, reducing the standing biomass. Second, the pathogen population will build up to the point of threatening trees that perhaps could resist a light attack but not a heavy infestation. The periods of extreme drought cause short- and medium-term loss of pine cone production, abortion of immature cones, loss of quality seeds and early cone opening. In the 2005 drought, all these factors caused the decline of the number of stored kernels in pine trees by more than 50 percent (Espelta, Arnan and Rodrigo, 2011). Scots pine (*Pinus sylvestris*) seems to be particularly sensitive to drought, suggesting that this pine species may become endangered in the Mediterranean basin especially in the relict stands of its southernmost location on isolated high mountains. Finally, there is also a risk from the invasion of non-native pathogens such as the *Bursaphelenchus xylophilus* that was found in Portugal for the first time in 1999. Sánchez-Humanes and Espelta (2011) focused on the effects of extreme drought on one of the most abundant trees in the Mediterranean, the oak (*Quercus ilex*), with rather inconclusive results. The authors found that a simple moderate decrease in precipitation (10 percent) reduced the number of productive trees by 25 percent and the number of the produced acorns by up to 50 percent. The same study also showed that traditional management practised in some of these forests to control density, such as clearing of sprouts, hardly diminishes the impact of drought on reproduction.

De Dios *et al.* (2007) suggested that “losses will probably be greatest for trees on the edges of their natural distribution where a small change will make the environment unsuitable for them” and that “some forest diseases now considered minor may become serious”. The increasing incidence of oak declines such as *Quercus ilex* L. (holm oak) may be a vivid example of climate change implications on forest health. It is hypothesized that the decline in holm oak in the Iberian Peninsula is due to *Phytophtora cinnamomi*, which requires wet soil conditions that are not met in this area. However, in the last few decades, floods have occurred more frequently, creating favourable conditions for the pathogen in these forests (De Luís *et al.*, 2001). These floods have been followed by drought events that have weakened the trees and made them more susceptible to the pathogen, resulting in higher mortality than ever before. A number of pathogens including *Ceratocysits ulmi* (Buism.) Moreau (Dutch-elm disease), *Hypoxylon mediterraneum* (De Not.) J. H. Miller (Hypoxylon canker) are likely to cause damage in southern Europe while *Heterobasidion annosum* (Fr.:Fr.) Bref. (Heterobasidion root rot) is likely to cause increasing damage in northern latitudes. The pine tent caterpillar (*Thaumetopoea pytiocampa*) may have increased effects on *P. sylvestris* or *P. halepensis* causing decreased seed production, seed mass and seedling survival. In the case of pine (*P. halepensis*), results show a direct relationship between extreme drought and loss of fertility of the pines.

As concerns species migration and displacement, early models forecasted shifts in forest biomes or ecosystems as intact entities and as a response to climate change. These models are no longer useful because plant communities are the result of interactions among organisms as well as among organisms with their abiotic environment, and thus climate change will not shift entire ecosystems but will alter species assemblage composition. Larger-scale effects of climate change include the biogeography of species with the most vulnerable being the forests of species grown at the margins of their geographic expansion in respect to soil moisture and temperature (Royce and Barbour, 2001). Regato (2008) argued that “the high heterogeneity of the Mediterranean landscapes, where a varied range of environmental conditions and a large ensemble of tree species and habitats with different optimum bioclimatic requirements are found within a very small area, may help considerably reduce dispersal distance requirements”. Research using simulations suggests that deciduous trees, such as *F. sylvatica* or *Quercus petraea* L. (sessile oak), would invade today’s subalpine belt displacing conifers that may migrate into today’s alpine zone if soils are suitable for forest growth. Aleppo pine (*P. halepensis*) may be a likely substitute for *Q. ilex* in the short term because it is more resistant to drought, although its populations are also expected to diminish under long-term drought conditions (Camara-Obregon 1998; Lloret and Siscart, 1995 cited in de Dios *et al.*, 2007). In mountain regions, certain species and communities could disappear completely because the upward displacement of species living close to the upper reaches of mountains will be constrained by the lack of any suitable habitat. This will affect agro-forest systems in mountainous areas. Early evidence of this may be seen in the southern slopes of the Pyrenees where the mountain pine is undergoing serious decline (de Dios *et al.*, 2007). In addition, with sea level rise, depending on the scenario, from 0.25 m to 1 m (Airoldi and Beck, 2007), there may be profound impacts on coastal ecosystems including coastal forests and coastal grasslands (Nicholls and Hoozemans, 1996).

However, the most serious effect of climate change, and especially of increased temperatures and summer droughts, is expected to be the risk of forest fires. Depending on the scenario, it is expected that, in southern Europe, climate change will increase forest fires by 10–20 percent (Carvahlo *et al.*, 2010). Giannakopoulos *et al.* (2009) show that, under a climate change scenario of a rise in temperature by 2 °C, forest fire risk increases considerably. This increase is higher during the summer, with the maximum in August and in the North Mediterranean inland while the Balkans, Maghreb, North Adriatic, central Spain and Turkey seem to be the most vulnerable regions; south of France is as strongly affected as Spain, but only in August and September, while the southeast Mediterranean (from Lebanon to Libya) sees no particular increase or decrease. Giannakopoulos *et al.* (2009) argue that this increase in fire risk is translated to 2–6 additional weeks of fire risk (i.e. more than a month) over all land areas with a significant proportion of this increase in fire risk being extreme fire risk. Forest fires on dry compacted soils expose the soil to high intensity storms resulting to soil erosion and nutrient loss and the consequent shift from forest cover to shrub land and bush land, especially in areas close to sub-desert zones and steppes. Forest fires will increase water runoff and contribute to the occurrence of extreme phenomena such as floods and landslides.

Giannakopoulos *et al.* (2009) used the Canadian Fire Weather Index (FWI) system to model fire risk under climate change conditions in the Mediterranean region. The Canadian FWI consists of six components that account for the effects of fuel moisture and wind on fire behaviour. The three components accounting for fuel moisture and wind include numeric ratings of the moisture content of litter and other fine fuels, the average moisture content of loosely compacted organic layers of moderate depth and the average moisture content of deep, compact organic layers. The three components accounting for fire behaviour include indices for the rate of fire spread, the fuel available for combustion, and the frontal fire intensity. The values of the FWI rise as the fire danger increases. Fire risk is low for FWI up to 15, and increases more rapidly with FWI more than 15. Giannakopoulos *et al.* (2005; 2009) selected a threshold of FWI more than 30 as a measure of increased fire risk, calculated the monthly changes of average FWI from May untill October between the future and the control period and found that: “The increase is higher during the summer, with the maximum increase in August in the North Mediterranean inland”, “Balkans, Maghreb, North Adriatic, central Spain, and Turkey seem to be the most vulnerable regions”, the “South of France is as strongly affected as Spain, but only in August and September”and the “southeast Mediterranean (from Lebanon to Libya) sees no particular increase or decrease”. In general, the increase in the mean FWI is translated into (Giannakopoulos *et al*., 2005; 2009):

- Two to six additional weeks of fire risk are expected everywhere except for Provence, southern Italy/Sardinia, northern Tunisia and Libya where one week more is foreseen, and Egypt and the Middle East coast where no increase is foreseen. A greater increase of up to 6–7 weeks is expected inland (central western Iberian Peninsula, the Atlas mountains and plateaus in North Africa, large parts of Serbia, Bosnia-Herzegovina and Montenegro in the Balkans, and northeastern Italy), where a significant proportion of this increase will actually be related to extreme fire risk. A smaller increase is expected in the coastal areas with almost no change in extreme fire risk, except for the Iberian Peninsula, Morocco, northern Italy and the eastern Adriatic coast.
- A significant proportion of this increase in fire risk is actually extreme fire risk (FWI more than 30).
- The maximum increase in fire risk will occur in July and August, especially in the central part of the Iberian Peninsula, northern Italy, the Balkans and central Anatolia.

Outside the summer months, fire risk increase is expected in May and October in the Iberian Peninsula, Morocco and Algeria, and only in May in southeastern Turkey and the Syrian Arab Republic.

- Significant increase in the number of days with fire risk (1–4 weeks), but not in the number of extreme fire risks for the South of France, and coastal areas of the rest of Mediterranean region.

Trigo (2012) argues that the last decade has been characterized by frequent heatwaves within the Mediterranean-European region, which have triggered a large number of wildfires, such as in Portugal (2003, 2005), Spain (2006), Italy and Greece (2007) and, more recently, Ukraine and the Russian Federation (2010). The 2003 heat wave was characterized by new all-time record values of maximum and minimum temperatures over Portugal in early August. These extreme temperatures and the associated low humidity values triggered the most devastating sequence of large fires ever registered in Portugal, with an estimated total burnt area of about 450 000 ha (Trigo *et al.,* 2006). In Israel, the frequency, intensity and extent of the fires would increase owing to the prolongation of droughts, increase in water evaporation and an increased frequency of intense heat waves. At a very moderate and conservative warming of 1.5 °C by the year 2100, models predict the desert to expand northward by 300 to 500 km. Mediterranean ecosystems, such as the one occurring in the Carmel Mountains, would disappear from Israel. For example, present day forest fires in the Carmel mountain range in northern Israel were preceded by eight months of drought and occurred during a heatwave with temperatures around 30 ºC. Normally, first rainfall should have come in September or October, and the maximal daily temperature at this time of year should be around 15–20 ºC. Lindner *et al*. (2008) argued that fire protection will be mainly important in the Mediterranean and temperate continental forests of Europe with different forest types requiring specific fire-management policies. They list a number of adaptation measures to enhance fire protection or to reduce risks of fire, including modification of forest structure (e.g. tree spacing and density, regulation of age class structure), removing standing dead trees and coarse woody debris on the forest floor, changing species composition, creating a mosaic of forest types including species with reduced flammability, and fuel management through thinning and biomass removals, grazing or the use of prescribed burning.

It is important to note that forest fires are associated with soil erosion, desertification and carbon sequestration owing to the significant effects that fires exercise on soils. In the Mediterranean region, fire is largely regarded as a major driving force of geomorphological processes, vegetation dynamics and landscape evolution. Additionally, wildfires impact a variety of soil properties. The magnitude, rate and type of most fire-affected processes are determined by the complex interactions between the physical, chemical and biological properties of the soil, as well as the characteristics of the fire itself. For example, following low to moderate fires, properties such as aggregate stability, pore size distribution and water repellency, together with the effects of ash and clogging of macropores, increase runoff and soil loss. However, following severe fires, the presence of wettable ash and the loss of surface water repellency may increase infiltration rates and accordingly decrease runoff and soil loss. Results from previous studies indicate that the most common chemical characteristics of fire-affected soils are organic matter, carbon, NPK minerals, cation exchange capacity, pH and buffering ability (Wittenberg, 2012). Certini (2005) has reviewed the effect of forest fires on soils and argues that low to moderate fires have little or no negative impacts (they rather eliminate undesired competitor species and increase pH and nutrient availability), but the enhancement of hydrophobicity can render the soil less able to soak up water and more prone to erosion. Severe fires can cause significant removal of organic matter, deterioration of both structure and porosity, considerable loss of nutrients through volatilization, ash entrapment in smoke columns, leaching and erosion, and marked alteration of both quantity and specific composition of microbial and soil-dwelling invertebrate communities (Lindner *et al.,* 2008).

5. RESILIENCE TO CLIMATE CHANGE

A sharp distinction should be made between mitigation and resilience. Mitigation refers to actions aiming at decreasing potential effects of global warming and consequent climate change. Resilience refers to actions aiming at building tolerance against the effects of global warming. Mitigation technologies and practices fall under three broad categories including reducing emissions, enhancing removals and avoiding or displacing emissions (Smith *et al.*, 2007). Bockel (2009) suggested that in agriculture, climate change adaptation refers to actions aiming to improve the resilience of the sector and reduce its vulnerability to changing climate. He also argues that, especially in agriculture, it is difficult to differentiate between mitigation and resilience measures, as these, very often, come together; indicatively, enriched carbon soils are resilient to drought and erosion, while carbon-fixing mitigation can induce rural income diversification, and thus strengthen economic resilience, especially in the case of poor rural households. However, the focus of this section is on resilience actions preparing agriculture and forestry to tolerate foreseen climate changes in southern Europe and the Mediterranean region. Examining resilience actions is a crucial step because, even if mitigation measures show signs of reducing greenhouse gas emissions, they will not be sufficient either to capture or to halt changes in temperature and precipitation rates. Thus, building resilience should be part of the strategic policy response to climate change (Iglesias, Quiroga and Diz, 2011; Iglesias *et al.*, 2011b).

In a recent study by the Institute for European Environmental Policy (Cooper and Arblaster, 2007) adaptation actions are distinguished in a two-fold manner. First, three broad categories are specified, namely behavioural, technological or management-based. For example, climate change will decrease water supply (lower precipitation) and increase demand (high temperatures and droughts) for irrigation water in the Mediterranean region, and thus methods of adapting to low water availability will become increasingly important. Such methods will require technological as well as managerial and behavioural solutions. From the technological point of view, a shift to water conservation on-farm may lead to the widespread adoption of drip irrigation techniques that also may imply a shift to liquid irrigation and new methods of applying plant protection substances. From a managerial and behavioural point of view, a shift to water conservation practices may include the adoption of drought-resistant crops, the adoption of water-saving cropping methods such as mulching, minimum tillage and maintenance of cover crops, a change in planting dates and cultivars, and even a shift to cropping zones by altitude and latitude. Other adaptations, largely unforeseen today, may be related to changing pest behaviour or to changing the demand for nitrogen-related fertilization owing to concentrations of atmospheric CO_2 that will increase nitrogen uptake by crops. Besides traditional plant breeding for producing new crop varieties, actions supporting resilience may include the adoption of farm management techniques for producing more nitrogen by leguminous crops and animal feeds, for example, roots, cereals and legume rich leys, in rotation (Kundzewicz *et al.*, 2007). Second, adaptation measures for agriculture are distinguished between short- and long-term options, depending on the magnitude of the change requited. Shorter-term agricultural adaptations include water conservation, changes in planting dates and cultivars, changes in external inputs and changes in animal housing systems. Longer-term adaptations include land-use changes, namely crop substitution, mostly induced by water scarcity and crop breeding, through the utilization of conventional genetics and biotechnology.

Giannakopoulos *et al.* (2009), whose climate change models for the Mediterranean region are extensively presented in section 2, examined the effects of two farm level climate change resilience strategies. They introduced in their crop yield simulations two adaptation measures that aim to cope with the impacts of global change, namely early sowing and shortening of growing season. Figure 9 shows that early sowing date (the grey bars), because it is associated with the shortening of the growing season (due to high temperatures), may reduce the negative impacts of climate change or even enhance positive impacts, allowing crops to escape higher temperature and water stress. For example, in the case of C3 summer crops in Egypt, early sowing is shown to produce significant positive effects out of slightly negative climate change effects. The use of longer growing cycle cultivars is a worthy adaptation practice because higher temperatures trigger increase of development rate. For example, the negative climate effects on legumes are reverted to positive for Tunisia, Libya and Greece, if longer growing cycles are adopted. Both adaptation practices, however, would require additional water for irrigation which re-connects farming practices to a wider water management strategy under climate change. The authors noted that, for example, the effective use of long-cycle cultivars can demand 25–40 percent more water, which may not be available or may not be a cost-effective measure under future climate change scenarios.

At the farm level, the adoption of resilience measures is a complicated issue and should not be regarded, by any means, as a panacea to climate change concerns. Important issues are related to the adoption of resilience measures at farm level. First is the identification of factors inhibiting or constraining the adoption of resilience measures. Second is the examination of whether action at farm level is adequate or should it be coupled and coordinated by actions at higher geographical and organizational levels. There are factors, exogenous and endogenous to the farm, that affect the intensity and time of the adoption of resilience measures at farm level. Factors related to the availability of innovations in technology and sciences (e.g. the availability of improved drought-resistant varieties) are purely exogenous to the farm. Factors related to farm practices are endogenous to the farm and depend on the learning curve of farmers in relation to climate change incidents.

As Meza and Silva (2009) have shown for Chile, farmers learn from past experience and dynamically adapt production to climate change. However, the form of the learning curve

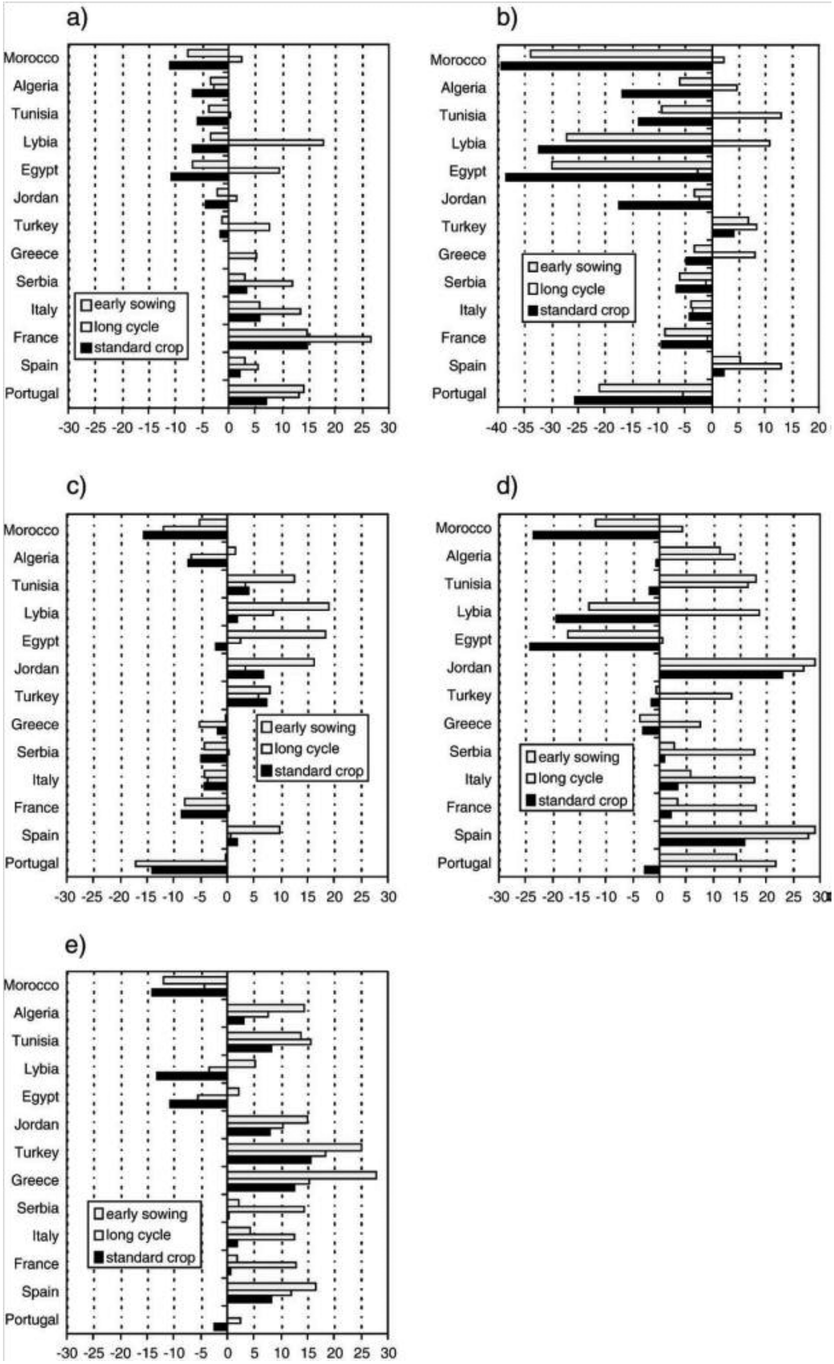

Figure 9. Impact of different crop adaptation options on crop responses under climate change for: (a) C4 summer crop, (b) legumes, (c) C3 summer crop, (d) tuber crops, (e) cereals

The changes reported in the figures are expressed as percent and obtained as differences between the mean yields of the two futures scenarios and the present yields.

Source: Figure 10 in Giannakopoulos *et al.,* (2009).

differs from farmer to farmer and depends on the capacity and skills that farmers have to assimilate changes. In general, the likely success of resilience measures at farm or sectoral level depends on a range of socio-economic factors including farm characteristics, such as production type, size of the farm, level of intensity, the diversity of cropping and livestock systems, the presence of other income sources apart from agriculture, access to relevant information, skills and knowledge about climate trends and adaptive solutions, the role played by advisory services in facilitating adaptation, the general socio-economic situation (with farmers with limited resources or living in remote rural areas being most vulnerable) and access to available technology and infrastructure capacity (European Commission, 2009a).

The adoption of resilience measures at farm level should not be left uncoordinated at local and regional levels because not all resilience measures are internally coherent and always consistent with wider, non- agricultural objectives at regional level. One example of internal incoherency was pointed out above, where the adoption of long-cycle cultivars increases demand for water. As such, a resilience measure adds stress to water resources, the existence of which forms the basis for a range of other resilience measures. In addition, and despite their potential to maintain the productive capacity of agriculture, several adaptation measures affect biodiversity, often negatively. Indicatively, in the Mediterranean region, irrigation is a key adaptation strategy, often associated with significantly negative biodiversity impacts. Increased irrigation may threaten several protected sites, especially RAMSAR Convention sites, by reducing water directed to these sites below the minimum ecological allotment or by directing to them water that will be increasingly polluted from fertilizers. On the other hand, the adoption of resilience measures at farm level, if appropriately coordinated, may maximize the positive impacts of the soil conservation strategies against soil erosion and desertification. For example, conservation tillage, which is the practice of leaving some or all of the previous season's crop residues on the soil surface, is a water conservation measure because it increases moisture by reducing evaporation and increases infiltration of rainwater into the soil. At the same time, it leaves a protective cover on the soil against extremely heavy rains or other extreme events (wind, drought, etc.) and thus protects the soil against water and wind erosion. All the aforementioned concerns raise the issue of a carefully designed resilience strategy at regional and even national levels.

Indeed, many researchers argue that there are limits to the effectiveness of simple farm-level resilience measures under more severe climate changes, which may call for more systemic changes in resource allocation (Howden *et al.*, 2007). For example, Bockel (2009) argues for a "country focus", integrating adaptation and mitigation into national sectoral policies and strategies, and for an "implementation focus" through the formulation and scaling up of projects and programmes. A "country focus" should aim at the consolidation of the resilience of cropping systems (through crop type diversification, development of more tolerant varieties, encouragement of crop rotations and crop systems with low reliance on fertilizers and pesticides), of watersheds and infrastructure to natural disasters (through reforesting degraded areas, maintaining water drain channels and developing local watershed/land-use plans) and of vulnerable populations to shocks (through the activation of national risk management systems including monitoring, forecasting and warning systems, as well as exposure-minimizing infrastructures, insurance and emergency response capacity). A wide range of public services and support policies is advocated in order to facilitate these agricultural resilience policy targets. In turn, an "implementation focus" could involve the *ex ante* project and programme appraisal of carbon balance, the enhancement of the poverty reduction potential, food security and sustainable development through payments for environmental services and the strengthening of productive, social and environmental safety nets.

Further, it has been pointed out that the choice and effectiveness of resilience measures vary owing to differentiation of and interactions between climate, environmental, cultural, institutional and economic factors. Thus, in a wider context, the design and application of measures can be "placed" into a wider strategic framework influenced by economic, political, institutional and social factors, as well as by interactions with the objectives of a rather broad set of policies (Cooper and Arblaster, 2007). Such a perspective has raised discussions on several issues. These include the links between small-scale/short-term responses that are often popular with farmers, and large-scale/longer-term options, which are associated with higher uncertainty at the micro level but can be more reliably projected with existing tools and thus have a potential to facilitate concrete policy decisions. Also, complex contexts and interactions have raised arguments for closer links between adaptation policies and other public intervention domains associated with sustainable development, and even for the mainstreaming of adaptation into planning for a wide range of policies. Other issues raised include the effective integration of mitigation and adaptation, the provision of information to governments and industries on investment decisions associated with efforts to combat climate change, the rewarding of early adopters and a focus on climate risk management. In a wider sense, a change in policy design and implementation has been advocated in order to improve adaptation effectiveness and adoption; this could involve deliberate, dynamic local, regional, national and international responses in a range of activities including infrastructures, community and institutional capacity-building and, generally, modifications to the decision-making environment associated with management-level adaptation activities (Howden *et al*., 2007).

In a European Union (EU) context, the well-established agricultural policy has facilitated the entering of climate change in the lexicon of the Common Agricultural Policy (CAP). Initially, the European Commission granted incentives for growing energy crops. Then, it facilitated the building of resilience measures at sectoral level, beyond the aforementioned farm-level measures (European Commission, 2009a). In this context, it was argued that sector-wide planning and advice are necessary, because some of the measures for adjusting to new climatic conditions are likely to be costly and may need significant investments by farmers, thus indirectly raising an issue of disproportionate resilience costs. Examples of sectoral-level adaptation actions include the identification of vulnerable areas and assessment of needs and opportunities for changing crops and varieties in response to climate trends; support to agricultural research and to experimental production aiming at crop selection and development of varieties best suited to new conditions; investment in improved efficiency of irrigation infrastructure and water-use technologies; building adaptive capacity by awareness-raising and provision of salient information and advice on farm management; developing irrigation plans based on thorough assessments of their impacts, future water availability and water needs of different users, taking account of the balance between demand and supply; developing risk and crisis management instruments to cope with the economic consequences of climate-driven events.

Through the radical 2003 reform of the CAP and the 2008 “Health Check” agreement (European Commission, 2009b), more emphasis was given to sustainable development of EU agriculture from both an economic and environmental perspective. In terms of income support, the decoupling of agricultural support from production factors allowed farmers to orient production decisions according (also) to biophysical conditions affected by climate change. Also, cross-compliance requirements (extended by the “Health Check”) contribute to the sustainable use of resources and adaptation, while Farm Advisory Systems and risk management tools can also be effective tools for sustaining adaptation in EU farms. CAP support to farmers’ adaptation efforts is also granted through the EU Rural Development Policy (RDP). In the case of the 2007–2013 programming period, both strategic and regulatory documents (European Commission, 2005; 2006b) contain explicit references to EU objectives for climate change mitigation. RDP measures with a potential to sustain adaptation to climate change include farm modernization, restoring agricultural production potential, improvement and development of infrastructure, adding value to agricultural and forestry products, agri-environmental schemes, support to LFAs and investment in human capital. Furthermore, since 2009, the implementation of the “Health Check” agreement included climate change mitigation and adaptation, renewable energy, water management and biodiversity among “New Challenges for European Agriculture” and directed additional financial support towards RDP measures pursuing such priorities.

The CAP post-2013 legal proposals and, more specifically, the proposal for the post-2013 RDP Regulation (European Commission, 2011) seems to signal an even higher focus of the CAP towards climate change adaptation and mitigation. The proposal specifies climate change adaptation and mitigation as a cross- cutting objective of rural policy, and defines the support of the shift towards a low carbon and climate resilient economy in agriculture, food and forestry sectors, as one of six EU RDP priorities, linking it with the following thematic programming objectives:

- increasing efficiency in water use by agriculture;
- increasing efficiency in energy use in agriculture and food processing;
- facilitating the supply and use of renewable sources of energy, of byproducts, wastes, residues and other non-food raw material for purposes of the bio-economy;
- reducing nitrous oxide and methane emissions from agriculture;
- fostering carbon sequestration in agriculture and forestry.

Further, it emphasizes the role of agri-environmental payments (which are now termed as agri- environment-climate payments) in encouraging farmers to introduce or continue to apply agricultural practices contributing to climate change mitigation and adaptation, and introduces a “new” risk management measure to assist farmers in addressing the most common risks, including climate change. It also defines that “Member States have to allocate at least 25 percent of their total RDP spending for climate change mitigation and adaptation and land management, through the agri-environment-climate, organic farming and payments to areas facing natural or other specific constraints measures". Despite the rather obvious higher attention of the post-2013 RDP to climate change adaptation and mitigation action, one cannot ignore that past criticism on the lack of dedicated measures responding to climate change (Cooper and Arblaster, 2007) is perhaps still valid. Also, first evidence on 2007–2013 financial allocations to the climate change "New Challenge" does not indicate any considerable utilization of such an option in Southern European Member States, which in turn seem to have followed past practices (Iglesias *et al*., 2007) and remain quite active in utilizing RDP resources for water management.

In Northern Africa, a recent report (OSS/UNEP, 2010) includes a compilation of existing and planned adaptation and mitigation measures that have occurred or will occur in North Africa. In the case of the rural land-use sector (agriculture/forestry), there seem to be rather few examples of planned adaptation measures.

There are some ad hoc examples of farmers and voluntary initiatives to improve farming practices, mostly driven by sustainable development policies at the local or regional levels. According to the report, reasons behind low uptake include uncertain information on climate change impacts and limited representation of farmers in decision-making processes. Both these factors undermine incentives to promote climate change adaptation. Of course, there are some success stories, including cooperative action on the restoration of degraded rangelands in Morocco and community-based organizations and action plans to improve land management in the degradation-prone dry lands of the Masreq and Maghreb countries. Taking account of the extrinsic link between development and adaptation, it is perhaps not surprising that the report emphasizes the importance of capacity building, synergy enhancement (i.e. integration of adaptation into development strategies and plans) and technology transfer. Especially for agriculture, a fundamental role for government in promoting resilience is advocated, as a means to improve information on projected climate change effects – information needed by farmers to design and build resilient farming systems and fill extension and educational gaps, which are quite common amongst the farming community.

De Dios *et al.* (2007) suggest a series of strategies for mitigating climate change impacts for the forest environment in the Mediterranean. The first is the "Conservation Management Strategy", which aims to prevent emissions and conserve current forest carbon pools through diminishing deforestation, increasing rotation period, reducing thinning intensity and restricting several harvesting activities. The second approach is the "Storage Management Strategy", a mitigation strategy aiming at increasing the amount of carbon stored in vegetation and soil. The third is the "Substitution Management Strategy", aiming at maximizing the time carbon is sequestered as wood. These strategies, although with a view to mitigating climate change impacts, include many adaptation measures. In general, for both agriculture and forestry, it is argued that in regions where adaptive capacity is high, negative climate change impacts will be dampened resulting in lower levels of risk. This may be the case of the Mediterranean region of Europe or Australia (Iglesias *et al.*, 2011a).

Taking into account the specificity and diversity of the aforementioned socio-economic factors in the Mediterranean basin, together with the fact that this region of the world is considered to be a climatic change hotspot, building a resilience strategy is a priority, "no regret" action. The prime aim of such a strategy should be to avoid the amplification of regional differences and the exacerbation of economic disparities between north-central and south European rural areas as well as among rural areas within the Mediterranean area.

6. SUMMARY AND CONCLUSIONS

Climate change in IPCC usage refers to a change in the state of the climate that can be identified (e.g. using statistical tests) by changes in the mean and/or the variability of its properties and which persists for an extended period, typically decades or longer. Climate change refers to present and future changes in climate conditions. Climate changes are more frequently reflected by increasing average temperature, changes in precipitation and changes in the frequency, intensity, spatial extent, duration, and timing of extreme weather and climate events.

The Mediterranean region presents a wide variability in climate change projections but the collective picture is one of substantial drying and warming. Especially in the warm season, precipitation decrease may exceed –25 to –30 percent and warming may exceed 4–50 °C (Giorgi and Lionello, 2008). Extreme events in the Mediterranean region are related to droughts and floods and the likely occurrence of both, i.e. extreme precipitation events after prolonged droughts, which may give rise to more extreme phenomena such as deep erosion and landslides. For these reasons, the Mediterranean region is identified as one of the most prominent hotspots in future climate change projections.

Climate change is assumed to have significant effects on Mediterranean agriculture. Projected climate changes will have a direct impact on water resources and irrigation requirements, crop growth conditions, crop productivity and crop distribution, agricultural pests and diseases control and the conditions for livestock production. These impacts will generate changing land-use patterns and will trigger economy-wide effects.

In the Mediterranean parts of Europe, the declining water balance has been documented over the past 32 years. Taking into account that demand for irrigation water in southern Europe and the Mediterranean area is already very high, under drier conditions more water will be required per unit area, and peak irrigation demands are expected to rise owing to droughts and high temperatures putting crops under severe stress. In certain areas of North Africa, rainfed agriculture represents more than 90 percent of total agricultural land. In certain North Africa and east Mediterranean countries, climate change may result in surface water reductions of more than 35 percent.

Crop growth is directly affected by CO_2 concentrations and soil moisture that is controlled by air temperature and precipitation. In southern Europe, general decreases in yield (e.g. legumes –30 to +5 percent; sunflower –12 to +3 percent and tuber crops –14 to +7 percent by 2050) and increases in water demand (e.g. for maize +2 to +4 percent and potato +6 to +10 percent by 2050) are expected for spring-sown crops. Extreme climate events during specific crop development stages (e.g. heat stress during flowering period, rainy days during sowing time), together with higher rainfall intensity and longer dry spells, are likely to reduce the yield of summer crops. The impacts on autumn-sown crops are more geographically variable. In general, the effect of climate change on crop growth is likely to be more severe in the southern Mediterranean areas than in the northern temperate areas. In the warmer southern Mediterranean, increases in CO_2 may help reduce the loss in yield arising from a warmer and drier climate, but may not be able to completely recover the losses. In the cooler northeastern Mediterranean, CO_2 increases associated with climate change result in little net effect on most crops, provided that the increase in water demand, especially for irrigated crops, can be met. Models based on demand and supply for food conclude that countries in the south of Europe, such as Spain, Portugal and Greece, will experience very large declines in agricultural areas that are much greater than the projected European-wide changes. These land-use allocations will create a large surplus of agricultural land and grasslands. The future management of this potential surplus of land will be a challenge.

Concerning grazing, higher temperatures result in greater water consumption and more frequent heat stress, which causes declines in physical activities, including eating and grazing. Livestock production may therefore be negatively affected in the warm months of the current warmer regions of Europe. Climate change impacts will probably be minor for intensive livestock systems. On the other hand, climate change and especially higher air temperatures will create conditions suitable for the invasion of weeds, pests and diseases adapted to warmer climatic conditions. Increasing temperatures may also increase the risk of livestock diseases by supporting the dispersal of insects, enhancing the survival of viruses from one year to the next and by improving conditions for new insect vectors that are now limited by colder temperatures.

The change in land productivity brought by changing climate conditions may trigger economy-wide effects. In areas with significant productivity losses such as the Mediterranean south, and with the agriculture sector still playing a significant role in the overall economy, GDP changes are expected to be negative and significant, especially under the A2 scenario. In the Mediterranean regions, the crop supply changes are negative, which results in higher prices and no gains for the agricultural trade balance. Especially in the Mediterranean south, the agricultural trade balance under the A2 scenario may deteriorate by almost 10 to 15 percent depending on the chosen climate model (HadCM or ECHAM).

Climate change, with its short- and long-term variation and gradual changes in temperature and precipitation, will apply an additional stress on rates of land degradation through changes in the length of days and/or seasons, recurrence of droughts, floods and other extreme climatic events, changes in temperature and precipitation that in turn reduces vegetation cover, water resource availability, and soil quality and changes in land-use practices, such as conversion of land use, pollution and depletion of soil nutrients. The impacts of climate change on storm runoff and erosion in Mediterranean watersheds are difficult to assess owing to the expected increase in storm frequency coupled with a decrease in total rainfall and soil moisture, added to positive or negative changes to different types of vegetation cover. The importance of soil conservation extends beyond sustaining economic, recreational and conservation activities to their role in carbon sequestration.

Climate change is expected to have significant, if not severe, impacts on Mediterranean ecosystems. Impacts can be categorized under three headings, namely, forest health, species migration and displacements, and forest fires and their consequent erosion and desertification. Climate change, by worsening climate conditions in the Mediterranean, will weaken forest stands, making them more susceptible to pathogens and allowing the pathogen population to build up to the point of threatening trees that could otherwise resist a light attack. Species migration and displacement are very complex processes and should not be examined under a naive mechanistic shift in the biogeography of species. It is argued that the high heterogeneity of the Mediterranean landscapes, where a varied range of environmental conditions and a large ensemble of tree species and habitats with different optimum bioclimatic requirements are found within a very small area, may help considerably to reduce dispersal distance requirements.

The most serious effect of climate change and especially of increased temperatures and summer droughts on forest is expected to be the risk of forest fires. Depending on the scenario, it is expected that in southern Europe, climate change will increase forest fires by 10–20 percent. An analysis based on the Fire Weather Index shows that the increase of serious fire risk is higher during summer, with the maximum increase in August in the North Mediterranean inland. The Balkans, Maghreb, North Adriatic, central Spain and Turkey seem to be the most vulnerable regions. The South of France is as strongly affected as Spain, but only in August and September, while the southeast Mediterranean (from Lebanon to Libya) sees no particular increase or decrease. Severe fires can cause significant removal of organic matter, deterioration of both structure and porosity, considerable loss of nutrients through volatilization, ash entrapment in smoke columns, leaching and erosion, and marked alteration of both quantity and specific composition of microbial and soil-dwelling invertebrate communities, making soils more prone to erosion and desertification.

Resilience refers to actions aiming at building tolerance against the effects of global warming. At farm level, a wide range of land-use and land management practices can facilitate tolerance. The adoption of drought-resistant crops, the adoption of water-saving cropping methods such as mulching, minimum tillage and maintenance of cover crops, a change in planting dates and cultivars and even a shift to cropping zones by altitude and latitude can assist farms to adapt to the changing climate. Other adaptations, largely unforeseen today, may be related to changing pest behaviour or to changing the demand for nitrogen-related fertilization due to concentrations of atmospheric CO_2 that will increase nitrogen uptake by crops. Thus, besides traditional plant breeding for producing new crop varieties, actions supporting resilience may include the adoption of farm management techniques for producing more nitrogen by leguminous crops and animal feeds, for example, roots, cereals and legume rich leys, in rotation. Building tolerance at farm level depends on the farmers' learning and adaptation abilities as well as on available technological and scientific innovations.

Resilience at farm level should be coordinated and planned to avoid possible internal incoherencies among resilience measures and inconsistencies of resilience with wider rural development objectives. Certain resilience measures are contradicting water conservation objectives and create internal incoherencies.

Other resilience measures can be better coordinated in the framework of wider objectives, such as the soil and water conservation strategies or biodiversity objectives and support and promote synergies with other actions at a higher geographical level (external consistency and synergy). In an EU context, the Commission facilitated the building of resilience measures at sectoral level, beyond the farm-level measures. In this context, it was argued that sector-wide planning and advice are necessary, because some of the measures for adjusting to new climatic conditions are likely to be costly and may need significant investments by farmers, thus indirectly raising an issue of disproportionate resilience costs. In Northern Africa, there seem to be rather few examples of planned adaptation measures and some ad hoc examples of farmers and voluntary initiatives to improve farming practices, mostly driven by sustainable development policies at the local or regional levels. The reasons behind low uptake of resilience measures include uncertain information on climate change impacts and limited representation of farmers in decision-making processes. Both these factors undermine incentives to promote climate change adaptation, although some success stories in Morocco and the Masreq and Maghreb countries denote the significant hidden capabilities of the rural population.

Taking into account the specificity and diversity of the aforementioned socio-economic factors in the Mediterranean basin, together with the fact that this region of the world is considered to be a climatic change hotspot, building a resilience strategy is a priority, "no regret" action.

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