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Climate change impacts in the Mediterranean resulting from a 2°C global temperature rise

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Climate change impacts in the Mediterranean resulting from a 2°C global temperature rise

Summary

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The goal of the present study is to provide the first piece of the puzzle in understanding the impacts of a 2°C global temperature rise on the Mediterranean region, using high temporal resolution climate model output that has been made newly available. The analysis has been based on the temperature, precipitation and wind daily outputs of the HadCM3 model using the IPCC SRES A2 and B2 emission scenarios. The study is focussed on the thirty-year period (2031-2060) centred on the time that global temperature is expected to reach 2°C above pre-industrial levels, as defined by an earlier companion study. Changes in both the mean (temperature, precipitation) and the extremes (heatwaves, drought) under the different scenarios were assessed. The impacts of these climatic changes on energy demand, forest fire, tourism and agriculture were subsequently investigated either using existing numerical models or an expert-based approach. Based on recent studies, the impacts on biodiversity, water resources and sea level rise in the region were also discussed.

Our results show that a global temperature rise of 2°C is likely to lead to a corresponding warming of 1-3 °C in the Mediterranean region. The warming is likely to be higher inland than along the coast. The largest increase in temperature is expected to take place in the summer, when extremely hot days and heatwaves are expected to increase substantially, especially in inland and southern Mediterranean locations.

Under the A2 scenario, a drop in precipitation seems to be the dominant feature of the future precipitation regime. Under the B2 scenario, rainfall increases in the northern Mediterranean, particularly in winter. However, under both scenarios precipitation decreases substantially in the summer in both the north and the south. In the south, the reduction in precipitation extends year round. Longer droughts are shown to be common, and are accompanied by shifts in timing. In terms of extremes, the number of dry days is shown to increase while the number of wet and very wet days remains unchanged. This

can imply that when it rains it will rain more intensely and strongly, especially at certain locations in the northern Mediterranean.

Based on the above climatic variables, we calculated the Canadian Fire Weather Index to provide an indication of the forest fire risk under the future climate scenarios. Under both A2 and B2 scenarios, fire risk is shown to increase nearly everywhere in the Mediterranean region, especially in inland locations. The southern Mediterranean is at risk of forest fire all year round. In the Iberian Peninsula, northern Italy and over the Balkans, the period of extreme fire risk lengthens substantially. The only region that shows little change in fire risk is in the southeastern Mediterranean.

Based on the same climatic data, we investigated the changes in agricultural crop yields using a well-established numerical model. Our results show a general reduction in crop yields (e.g. C3 and C4 summer crops, legumes, cereals, tuber crops). The southern Mediterranean is likely to experience an overall reduction of crop yields due to the change in climate. In some locations in the northern Mediterranean, the effects of climate change and its associated increase in carbon dioxide may have little or small positive impacts on yields, provided that additional water demands can be met. The adoption of specific crop management options (e.g. changes in sowing dates or cultivars) may help in reducing the negative responses of agricultural crops to climate change. However, such options could require up to 40% more water for irrigation, which may or may not be available in the future.

We calculated heating degree days (HDD) and cooling degree days (CDD) in order to examine the change in heating and cooling requirements. Under both climate scenarios, HDD decreases substantially in the northern Mediterranean and CDD increases everywhere in the Mediterranean, especially in the south. This change can potentially shift the peak in energy demand to the summer season with implications for the need for additional energy capacity and increased stress on water resources.

Changes to tourism in the Mediterranean were examined through discussions with experts and stakeholders. We expect that warmer northern European summers would encourage northern Europeans to take domestic holidays and thus, not travel to the Mediterranean. In addition, more frequent and intense heat waves and drought are likely to discourage holidays in the Mediterranean in the summer. We expect that the Mediterranean holiday season may shift to spring and autumn.

Based on results from existing studies, a global warming of 2°C and its associated reduction in precipitation are expected to reduce surface runoff and water yields in the Mediterranean region. In some countries, this could result in water demand exceeding available water supply. In terms of biodiversity, climate change is likely to lead to shifts in the distributions and abundances of species, potentially increasing the risks of extinction. In addition, forest fires are expected to encourage the spread of invasive species which in turn, have been shown to fuel more frequent and more intense forest fires.

Acknowledgments

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Contents:

Impact of a 2° C global temperature rise on the Mediterranean region: Agriculture analysis assessment.

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Summary
The climate change impact analysis on agriculture showed that the expected changes in temperature and precipitation for SRES-IPCC scenarios A2 and B2 in the time-slice 2031-2060 determined a general reduction in yield of agricultural crops (e.g. C3 and C4 summer crops, legumes, cereals, tuber crops). Reductions in yields are more severe in the southern Mediterranean than in the northern Mediterranean, even when the fertilizing effect of increased CO_2 is taken into account. The southern Mediterranean is likely to experience an overall reduction of crop yields due to climate change. In some locations in the northern Mediterranean, the effects of climate change and its associated increase in CO_2 may have little or small positive impacts on yields, provided that additional water demands can be met. The adoption of specific crop management options (e.g. changes in sowing dates or cultivars) may help in reducing the negative responses of agricultural crops to climate change. However, such options could require up to 40% more water for irrigation, which may or may not be available in the future.

Materials

Climate data. The daily climate data used for this study was obtained from the simulation results of the HadCM3 model developed by the UK Meteorological Office Hadley Centre. In particular, in order to reproduce the impact of a 2° C global temperature rise on the Mediterranean region, two time-slices 1961-1990 and 2031-2060 were considered to represent present and future climate, respectively. Further, two emission scenarios were selected among those proposed by the Special Report on Emissions Scenarios (SRES) (IPCC 2000): i) scenario A2, characterised by medium-high greenhouse gas emission; ii) scenario B2 characterised by medium-low greenhouse gas emission.

Statistical yield data. In order to select the most important crops for the different areas of the Mediterranean basin and to evaluate the capacity of the selected crop simulation model (i.e. CropSyst) to reproduce crop yields, the data reported in the FAOSTAT database (http://faostat.fao.org/) has been collected for Mediterranean countries.

Crop simulation model. CROPSYST is a multi-year, multi-crop, daily time step crop growth simulation model (Stockle et al, 2003). The model simulates the soil water budget, soil-plant nitrogen budget, crop canopy and root growth, phenology, dry matter production, yield, residue production and decomposition, and erosion. The model allows the user to specify management parameters such as sowing date, cultivar genetic coefficients (photoperiodic sensitivity, duration of grain filling, maximum leaf area index, etc.), soil profile properties (soil texture, thickness), fertilizer and irrigation management, tillage, atmospheric CO_2 concentration etc. The capability of the model to simulate crop yields has been evaluated in numerous field studies conducted in the Mediterranean, United States and Australia (Stockle et al., 2003). In general, the agreement between simulated and measured yields was good. When properly calibrated and applied, CropSyst has proved to be a suitable tool for simulating cropping systems.

Methods: ***Selection of the hot spots.*** Following the results of the climate analysis assessment performed in Section 5, by C. Giannakopoulos, thirteen grid cells (called 'hot spots') of the HadCM3 has been selected (Fig. 1). More specifically these grid cells (2.5° latitude by 3.75° longitude) were selected to provide an homogenous cover of the study area and to study the areas where changes in precipitation and temperature patterns are expected to be substantial, according to HadCM3 model simulations.

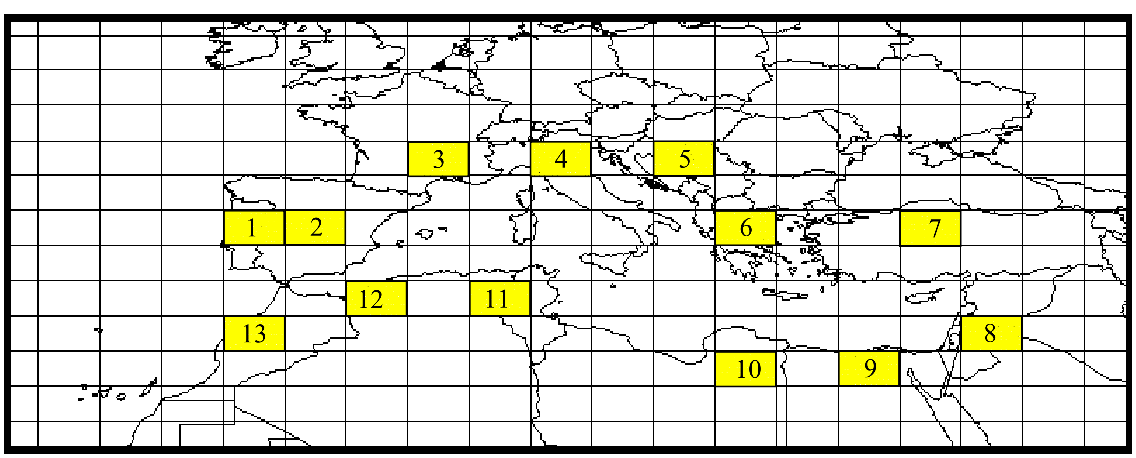

Figure 1 – Grid cells of Had CM3 selected for impact assessment on agriculture

Selection of the crops. The data reported on the FAOSTAT database was used to select the agricultural crops for each 'hot spot'. In particular, the selection of the species was based on the different characteristic of agricultural crops: i) photosynthesis pattern (C3 and C4 crops)[1], ii) growing period (winter an summer seasons), iii) food composition (protein, e.g. legumes and carbohydrates, e.g. tuber crops); and on the basis of the extension of the cultivated area in the countries that are included the grid cells (Tab. 1). No account has been taken of the introduction of new crops which may becomes suitable in these regions.

Table 1 – Type of crop simulated in each of the selected grid cell

Grid cell number	Country	C4 summer crop	C3 summer crop	Legumes	Tuber crops	Cereals
1	Portugal	maize	sunflower	bean	potato	wheat
2	Spain	maize	sunflower	lentil	potato	barley
3	France	maize	sunflower	soybean	potato	wheat
4	Italy	maize	sunflower	soybean	potato	wheat
5	Serbia	maize	sunflower	soybean	potato	wheat
6	Greece	maize	sunflower	bean	potato	wheat
7	Turkey	maize	sunflower	lentil	potato	wheat
8	Jordan	maize	sunflower	lentil	potato	barley
9	Egypt	maize	sunflower	bean	potato	wheat
10	Libya	maize	sunflower	bean	potato	wheat
11	Tunisia	maize	sunflower	bean	potato	wheat
12	Algeria	maize	sunflower	bean	potato	wheat
13	Morocco	maize	sunflower	bean	potato	wheat

Impact analyses. First of all the CropSyst model (Stockle et al. 2003) was calibrated to fit as much as possible the data reported on the FAOSTAT database (http://faostat.fao.org/). Then, for each 'hot spot' and crop type the annual values of development stages and yields were calculated for the two time-slices (1961-1990 and 2031-2060). In particular, for the present climate the simulation runs were done setting the atmospheric concentration of CO_2 at 350 ppm; whilst the simulation runs for the future climate scenarios were done without and with the effects of increasing CO_2 (470 ppm scenario B2 and 520 ppm scenario A2). The crop responses to increasing CO_2 was introduced in the simulation runs following the results obtained in the Free Air CO_2 Enrichment (FACE[2]) experiments (Kimball et al. 2002; Ainsworth and Long 2005). In general, results from FACE experiments show, as under field conditions, the effect of

[1] Almost all plant life on Earth can be broken into two categories based on the way they assimilate carbon dioxide into their systems. C3 plants include more than 95 percent of the plant species on earth (e.g. trees, wheat, sunflower). C4 plants include such crop plants as sugar cane and corn. During the first steps in CO_2 assimilation, C3 plants form a pair of three carbon-atom molecules. C4 plants, on the other hand, initially form four carbon-atom molecules. It turns out that under present CO_2 concentration (≈ 360 ppm) C4 plants are more economical in the use of water and have a much higher yield potential than C3 plants. However, it is expected that C3 plants can respond readily to higher CO_2 levels, and C4 plants can make only limited responses. Thus, increased CO_2 likely will mean that some plant species will be stronger, more prolific, and may overwhelm those less able to benefit.

[2] In FACE experiments, jets of CO2 are released over vegetation plots in the open-air through an array of pipes. Natural wind and diffusion disperse the CO_2 across the experimental area.

CO_2 on crop yields is significantly lower than that obtained in controlled environmental studies.

Finally, 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 the simulation runs the C4 summer crops (i.e. maize) and tuber crops (i.e. potato) were considered as “irrigated crops”, whilst the rest of the crops were considered as “rainfed crops”. Moreover, all the crops were considered fully fertilised (i.e. no nitrogen stress).

Results:

Crop yields under present climate The simulated crop yields for the present climate obtained by calibrating CropSyst model on the basis of the FAO data were reported in Fig. 2. The results showed a pattern of crop yields in rainfed crops (C3 summer crop, legumes, cereals) that is strongly correlated to the precipitation regimes of the different grid cells. Hence, lower crop yields were seen in regions of Northern Africa which is expected to have lower water availability. Whilst for the irrigated crops (C4 summer crops and tuber crops) the differences in crop yields among the grid cells were less evident and these were mainly driven by the temperature regimes.

In order to provide a quantitative estimate of the uncertainties related to the capacity of CropSyst to simulate crop yields, Mean Absolute Errors (MAEs) were calculated for each crop type in four main regions in the Mediterranean (Table 2). Mean absolute error is the average of the difference between modeled and observed value in all test cases and can be considered as the average prediction error for CropSyst simulations for ths study. MAEs also include inherent errors that arise from the comparison of model output with observed data. Simulated values from CropSyst are calculated for individual grid cells while the statistical data from FAO has been collected at the nation level. The climate conditions of the grid cells cannot completely represent the average condition over a nation, and the statistical data also include sources of variability (e.g. technological trend, pest and disease stresses, etc.) that cannot be reproduced by the model.

Table 2. Mean Absolute Error (MAE, %) between observed and simulated crop yields for the main Mediterranean regions: N-W = Portugal, Spain, France and Italy, N-E = Serbia, Greece and Turkey, S-E = Jordan, Egypt and Libya, S-W = Tunisia, Algeria and Morocco

	Mean Absolute Error (MAE, %)				
Region	**C4 summer**	**Legumes**	**C3 summer**	**Tuber crops**	**Cereals**
N-W	9.3	4.6	10.8	8.7	9.8
N-E	4.4	1.4	2.1	6.7	4.3
S-E	12.1	13.8	4.4	11.7	1.3
S-W	13.4	0.9	2.7	3.3	6.4

Table 2 shows that CropSyst results match quite closely with the statistical data collected by FAO, with MAEs ranging from less than 1% to under 14%. The MAEs can also be used as a measure of the uncertainties of crop yield estimates due to the bias between observed and simulated yields. The total uncertainty is likely to be larger due to the uncertainties cascaded from the emission scenarios and the global climate model (see Section 4.4 for a discussion of uncertainty cascades).

Changes in crop yields without the effect of CO_2

The results of the CropSyst simulation runs (without including the effect of CO_2) for present and future climate scenario were reported in Fig. 3. On the basis of the different crop types these are the main results:

- ***C4 summer crops.*** C4 summer crops showed an almost systematic reduction of yields with the exception of a few grid cells located in the EU-Mediterranean countries (e.g. Italy, France, Spain and Portugal). More specifically, these ranges from -15% (Morocco) to + 10% (France) in A2 scenario and from -13% (Morocco) to +9% (France) in B2 scenarios (Fig. 3a).
- ***Legumes.*** Legumes showed a general reduction of yields in all the grid cells with the exception of that on Spain, where, however, the increase was very small. More specifically, these changes ranges from -44% (Morocco) to -13% (Turkey) in A2 scenario and from -45% (Egypt) to +3% (Spain) in B2 scenarios (Fig. 3b).
- ***C3 summer crops.*** C3 summer crops showed a general reduction of yields in all the grid cells with the exception of that on Spain, where, however, the increase was very small. More specifically, these changes ranges from -32% (Portugal) to -6% (Jordan) in A2 scenario and from -23% (Morocco) to +1% (Spain) in B2 scenarios (Fig. 3c).
- ***Tuber crops.*** Tuber crops showed a general reduction of yields in all the grid cells with the exception of those on Jordan and Spain. More specifically these changes ranges from -35% (Morocco) to -1% (Jordan) in A2 scenario and from -31% (Egypt) to +15% (Spain) in B2 scenarios (Fig. 3d).
- ***Cereals.*** Cereals showed a general reduction of yields, even if in a few grid cells the yields increased (Turkey, Greece and Spain). More specifically these changes ranges from -23% (Morocco) to -2% (Turkey) in A2 scenario and from -24% (Libya) to +8% (Turkey) in B2 scenarios (Fig.3e).

The general picture showed a substantial reduction for all the crop types in all the 'hot spots' grid cells. This was due to the increases in temperature and reduction in precipitation predicted for both future climate scenarios (A2 and B2), that determined a reduction of the length of the growing period (i.e. higher rate of crop development) (Tab. 3) and the water available for crop growth, respectively. These decreases were higher in summer and not irrigated crops (e.g. C3 summer crops, legumes), since the reductions in precipitation are expected to be higher during the summer periods. Moreover, in general the reductions were higher in A2 scenarios, since for this scenario larger changes in temperature (increase) and precipitation (reduction) regimes were expected. However, the results from the two scenarios agree closely in terms of maximum decreases in yields.

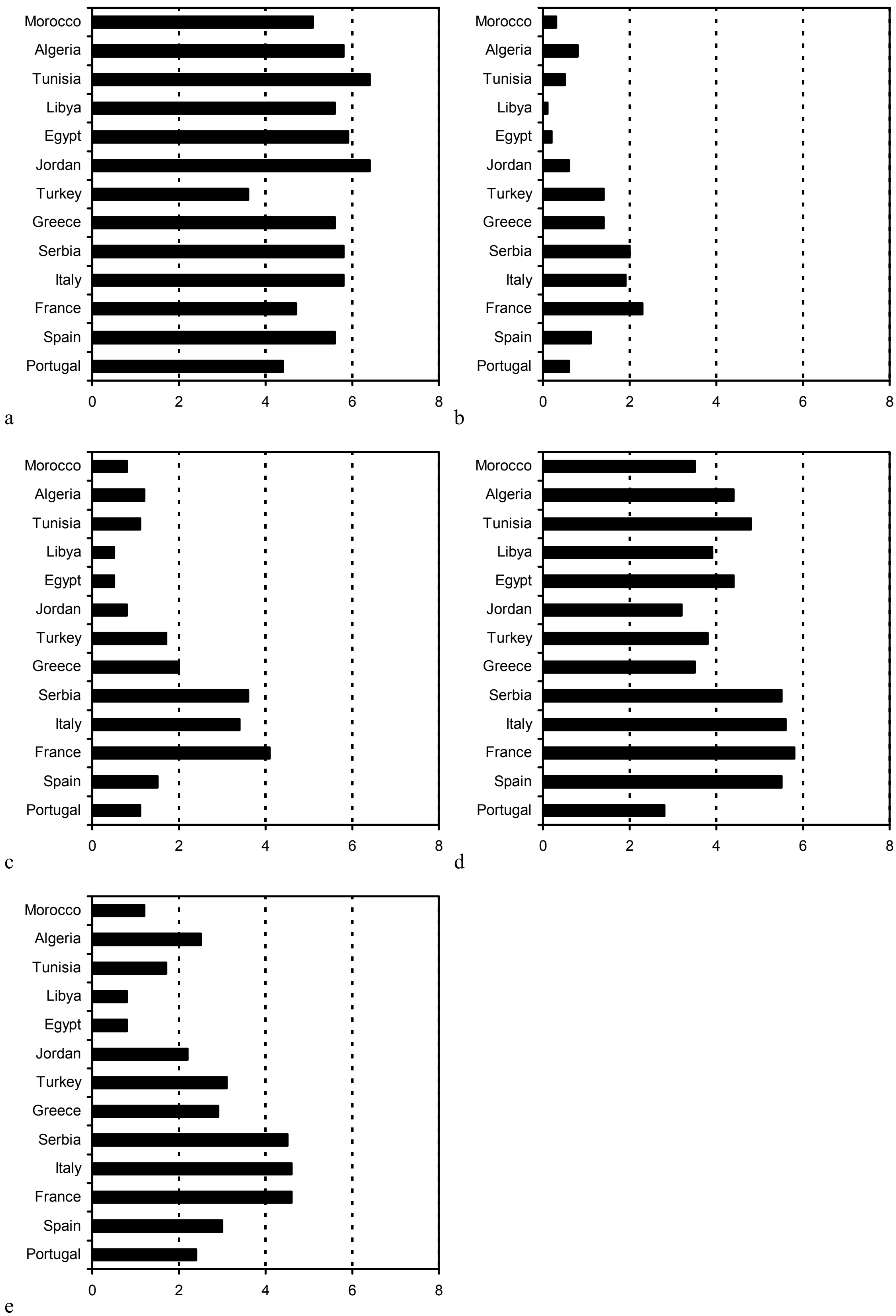

Figure 2- Crop yields (t ha^{-1}) in the selected 'hot spots' grid cells: a) C4 summer crop, b) legumes, c) C3 summer crop, d) tuber crops, e) cereals.

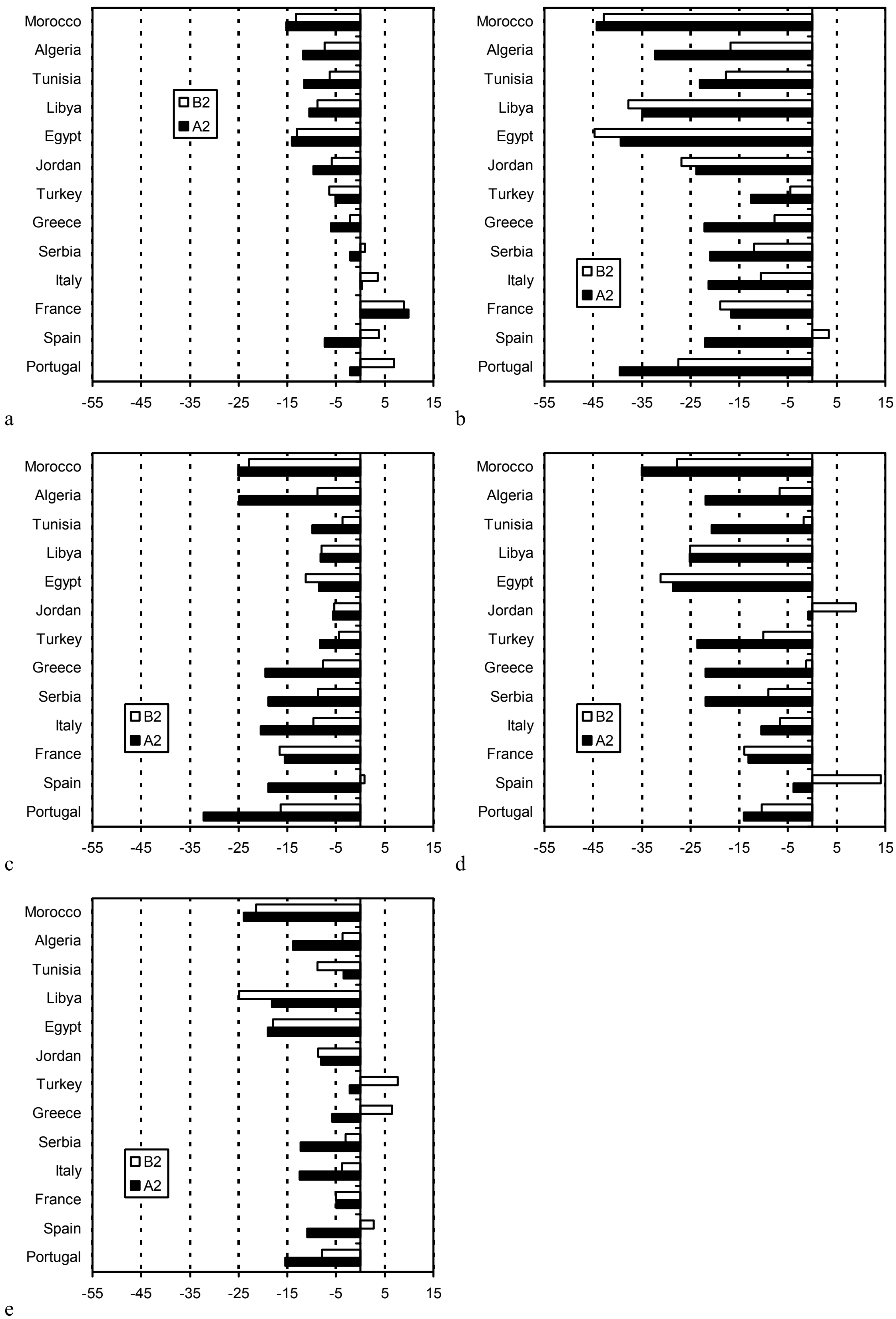

Figure 3- Impact of climate change on crop yields without CO_2 effect: a) C4 summer crop, b) legumes, c) C3 summer crop, d) tuber crops, e) cereals. The changes reported in the figures were expressed as % and obtained as differences between the mean yields of the two futures and the present yields.

Table 3 – Mean length of the growing season for the different crop types under the present climate scenario and mean percentage changed under future scenarios

Crop type	Length (days)	A2 (% change)	B2 (% change)
C4 summer crop	126.3	-8.0	-7.5
C3 summer crop	131.2	-6.7	-6.4
Legumes	108.0	-5.9	-5.7
Tuber crops	170.4	-5.5	-4.7
Cereals	214.0	-1.7	-1.8

Changes in crop yields with the effect of CO_2

The results of the CropSyst simulation runs (including the effect of CO_2) for present and future climate scenario were reported in Fig. 4. On the basis of the different crops types these are the main results:

- ***C4 summer crops.*** C4 summer crops showed a prevalent reduction in yields in the grid cells located in the African and Asian Mediterranean countries (e.g. Morocco, Tunisia, Jordan, etc.); whereas on the European grid cells yields showed a consistent increase. More specifically, these changes ranges from -12% (Morocco) to + 16% (France) in A2 scenario and from -11% (Egypt) to +13% (France) in B2 scenarios (Fig. 4a).
- ***Legumes.*** Legumes showed a general reduction of yields in all the grid cells with the exception of those on Spain, Turkey and Greece. More specifically, these changes ranges from -39% (Morocco) to +2% (Turkey) in A2 scenario and from -41% (Egypt) to +15% (Spain) in B2 scenarios (Fig. 4b).
- ***C3 summer crops.*** C3 summer crops showed a general reduction of yields in the grid cells located on Northern and South-western shores of the Mediterranean basin; whereas in the grid cells located on the Southern or Eastern shores, yields were substantially unchanged. More specifically, these changes ranges from -21% (Portugal) to +6% (Turkey) in A2 scenario and from -16% (Morocco) to +11% (Spain) in B2 scenarios (Fig. 4c).
- ***Tuber crops.*** Tuber crops showed an inconsistent response among selected grid cells, with a general reduction of yields in those on the African shores of the basin, and prevalent increase in the rest. More specifically these changes ranges from -25% (Morocco) to +16% (Jordan) in A2 scenario and from -27% (Egypt) to +30% (Jordan) in B2 scenarios (Fig. 4d).
- ***Cereals.*** Cereals showed a prevalent increase in yields. More specifically these changes ranges from -15% (Morocco) to +13% (Tunisia) in A2 scenario and from -19% (Libya) to +19% (Turkey) in B2 scenarios (Fig. 4e).

The general picture showed that the effect of climate change on agriculture in tropical areas are likely to be more severe than in temperate areas, even when the fertilizing effect of increased CO_2 is considered (Table 4). In the warmer southern Mediterranean, increases in CO_2 help to reduce the loss in yield arising from a warmer and drier climate, but is not able to completely offset the losses. In the cooler northeastern Mediterranean, CO_2 increase and the associated climate change result in little net effect on most crops, provided that the increase in water demands, especially for irrigated crops, can be satisfied (Table 4). Similarly in the northwestern Mediterranean, yields of irrigated crop may increase if water demands can be met. However, rainfed summer crops are likely to experience a net reduction in yield, even when the fertilizing effect of CO_2 is considered.

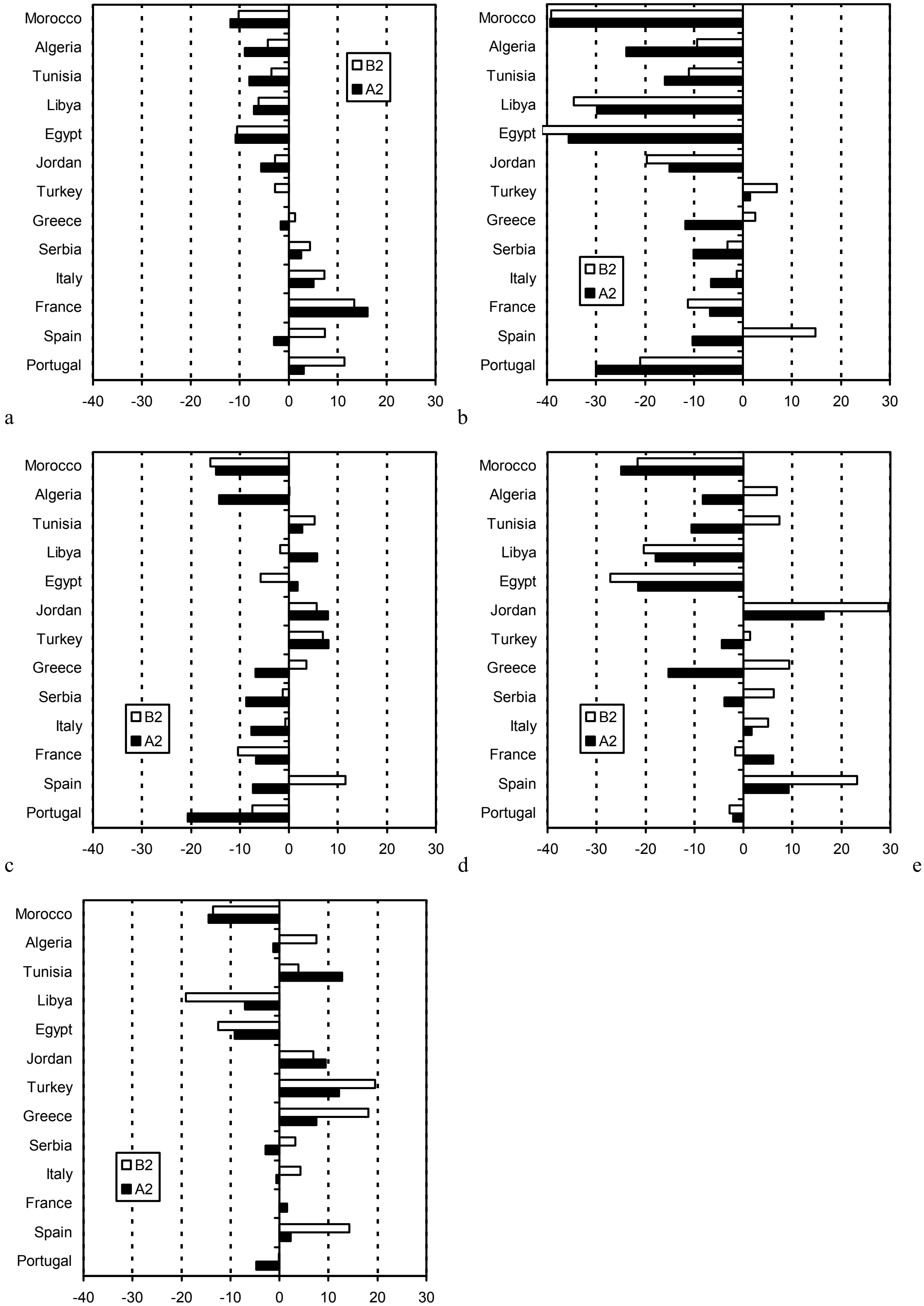

Figure 4- Impact of climate change on crop yields with CO_2 effect: a) C4 summer crop, b) legumes, c) C3 summer crop, d) tuber crops, e) cereals. The changes reported in the figures were expressed as % and obtained as differences between the mean yields of the two futures and the present yields.

Table 4 – Percentage changes of crop yields for the main Mediterranean regions: N-W = Portugal, Spain, France and Italy, N-E = Serbia, Greece and Turkey, S-E = Jordan, Egypt and Libya, S-W = Tunisia, Algeria and Morocco

		Without CO_2		**With** CO_2	
		A2-A	**B2-A**	**A2-A**	**B2-A**
C4 summer	N-W	0.19	5.80	4.19	8.78
	N-E	-4.43	-2.54	-0.60	0.21
	S-E	-11.44	-9.26	-7.89	-6.70
	S-W	-12.87	-8.94	-9.38	-6.37
Legumes	N-W	-24.90	-13.42	-14.38	-4.86
	N-E	-18.59	-8.11	-7.19	0.97
	S-E	-32.72	-36.43	-23.30	-30.15
	S-W	-33.26	-25.81	-23.92	-18.48
C3 summer	N-W	-21.79	-10.44	-12.41	-2.85
	N-E	-15.57	-6.92	-5.44	0.96
	S-E	-7.44	-8.19	3.66	-0.41
	S-W	-19.94	-11.81	-10.33	-4.34
Tubers	N-W	-10.37	-4.24	4.87	7.53
	N-E	-22.50	-6.80	-9.33	4.39
	S-E	-18.22	-15.77	-4.31	-5.66
	S-W	-25.88	-12.10	-13.28	-1.55
Cereals	N-W	-10.97	-3.49	-0.29	4.68
	N-E	-6.79	3.71	4.39	12.49
	S-E	-15.08	-17.17	-4.88	-10.15
	S-W	-13.77	-11.29	-3.42	-3.77

Impacts of adaptation options

The results of the CropSyst simulation runs (including adaptation strategies) for present and future climate scenarios were reported in Fig. 5. On the basis of the different crops types these are the main results:

- ***C4 summer crops.*** C4 summer crops showed that the introduction of cultivars with a longer growing cycle or the early sowing of standard cultivars determined positive effects on crop yields. More specifically, the average changes of yields passed from – 1% with standard cultivar to +1% and +9% with an early sowing and cultivar with longer growing cycles, respectively (Fig. 5a).
- ***Legumes.*** Legumes showed that the introduction of an early sowing of standard cultivars determined positive effects on crop yields. More specifically, the average changes of yields passed from – 15% with standard cultivar to -10% and +4% with an early sowing and cultivar with longer growing cycles, respectively (Fig. 5b).
- ***C3 summer crops.*** C3 summer crops showed that the introduction of an early sowing of standard cultivars determined positive effects on crop yields. More specifically, the average changes of yields passed from – 3% with standard cultivar to +5% and -1% with an early sowing and cultivar with longer growing cycles, respectively (Fig. 5c).
- ***Tuber crops.*** Tuber crops showed that the introduction of cultivars with a shorter growing cycle or the early sowing of standard cultivars determined positive effects on crop yields. More specifically, the average changes of yields passed from – 3% with

standard cultivar to +16% and +6% with cultivars with longer growing cycles an early sowing, respectively (Fig. 5d).
- ***Cereals.*** Cereals showed that the introduction of cultivars with a longer growing cycle or the early sowing of standard cultivars determined positive effects on crop yields. More specifically, the average changes of yields passed from +1% with standard cultivar to +8% and +9% with cultivars with longer growing cycles and early sowing, respectively (Fig. 5e).

The introduction of adaptation strategies showed the possibility to reduce the negative effects determined by the changes in climate conditions. Anticipation of the sowing date may allow the crops to escape the water stress during the late period of the growing cycle. Cultivars with longer growing period may increase the length of the filling of reproductive organs that under future climate is expected to be shorter for the increasing temperature. Both options, however, would require additional water for irrigation. In particular, the effective use of long cycle cultivars can demand 25 – 40 % more water (Table 5), which may or may not be available in the future.

Table 5 - Mean percentage changes of water supply for irrigated crops under future scenarios for different adaptation options

Crop type	**Scenario A2**			**Scenario B2**		
	Standard (%)	Early sowing (%)	Long cycle (%)	Standard (%)	Early sowing (%)	Long cycle (%)
C4 summer crop	2.9	3.6	25.1	2.6	2.6	26.5
Tuber crops	7.0	9.6	43.7	7.8	8.3	41.0

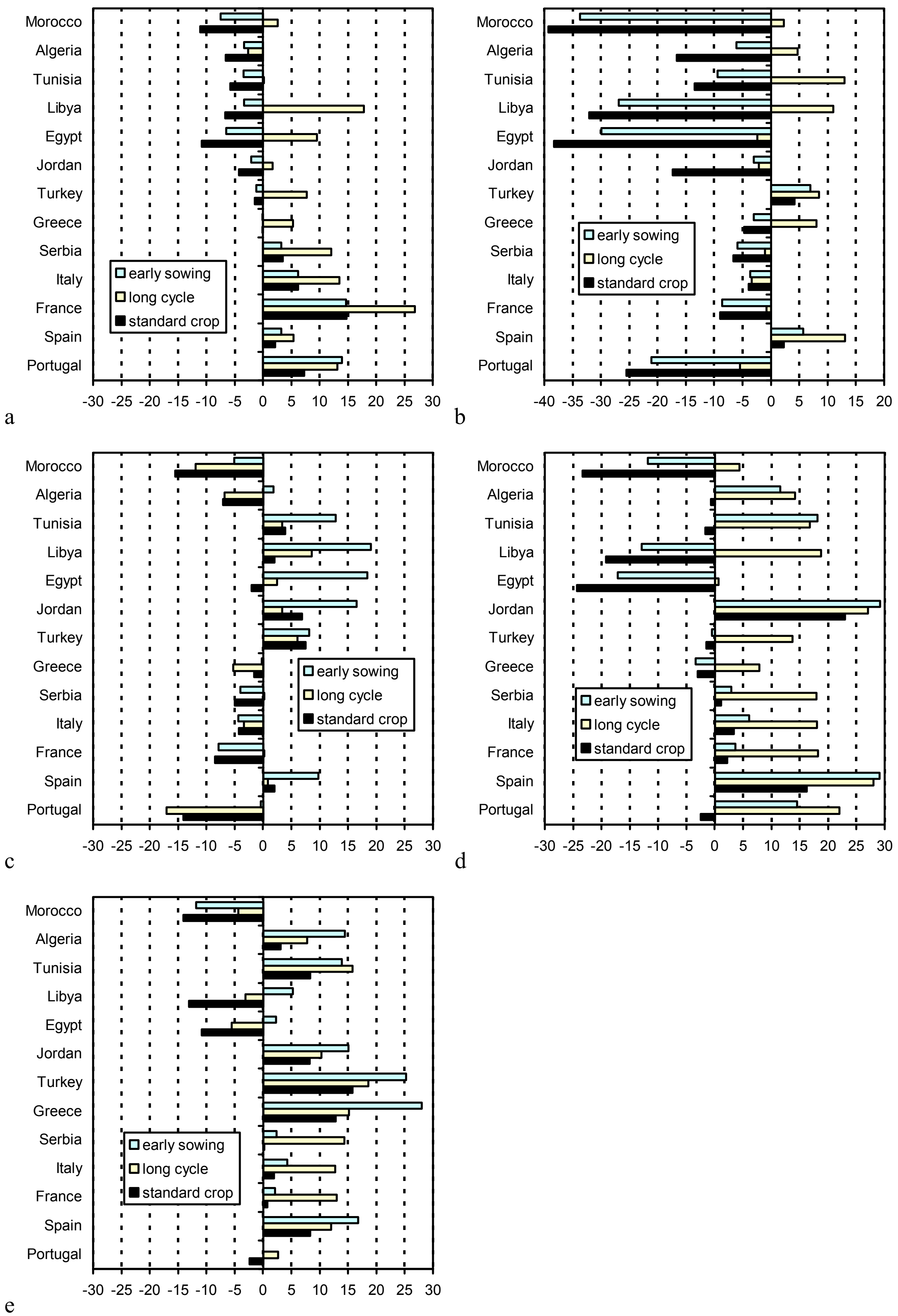

Figure 5 - Impact of different crop adaptation options on crop responses under climate change: a) C4 summer crop, b) legumes, c) C3 summer crop, d) tuber crops, e) cereals. The changes reported in the figures were expressed as % and obtained as differences between the mean yields of the two futures and the present yields.

Discussions and Conclusions

Our study showed that the increases in temperature and reduction in precipitation predicted for both future climate scenarios (A2 and B2) lead to a substantial reduction of yields for all the crop types in all the 'hot spots' grid cells, through the reduction of the length of the growing period and the water available for crop growth. Reductions in yields are more severe in the warmer southern Mediterranean than in the cooler northern Mediterranean, even when the fertilizing effect of increased CO_2 is taken into account. The southern Mediterranean is likely to experience an overall reduction of yields due to climate change. In some locations in the northern Mediterranean, the effects of climate change and its associated increase in CO_2 may have little or small positive impacts on yields, provided that additional water demands can be met.

Strategies such as early sowing dates or cultivar with slower development rates may be considered as helpful options to reduce some of the reductions in crop yield determined by the changes in climate conditions. However, such options could require up to 40% more water for irrigation, which may or may not be available in the future.

Moreover, according to recent studies on the effects on crop yields of tropospheric pollutants such ozone, there is reason to believe that our estimates of yield losses under a future scenario may be conservative. Current and increased concentrations of ground level ozone have been shown to lead to decreases in plant biomass and yield (Morgan et al., 2003; Gitay et al., 2001). Independently of climate change, but exacerbated by it, surface ozone concentrations are expected to increase globally. Thus, if the effects of ozone are to be included in an assessment of crop yields in the Mediterranean under a future climate scenario, the results are likely to greater yield reductions than presented in this report.

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