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1. **INTRODUCTION**

This document represents the achievement of the task T4.4.3 focussed on the adaptation measures in agriculture to face water-related security treats in Case Study (CS) areas.

The activities are focused on the specific adaptation measures that should take into consideration the water availability and water sharing among different sectors in Case Study areas. Both scenarios (baseline year 2000 and reference year 2050) are taken into consideration. Accordingly, the databases characterizing the agricultural production in CS areas have been developed (D4.4.1) using the outputs of WP2 and the inputs from the CS areas. The adaptation measures have been identified and quantified by means of best management options and volumes of water that could be saved for each Case Study area.

The possible options included the adoption of deficit irrigation strategies, shifting of growing season, introduction of new less-water demanding crops and/or long maturing varieties (LMV), etc. Crop Water Requirements (CWR) and Irrigation Requirements (IR) have been estimated for each scenario distinguishing between the options to be adopted due to climate change only and those regarding the specific extreme events. The adaptation measures and water saving options have been elaborated by using the same models applied in T4.4.2. The overall results have been obtained assembling the outputs from different models. These outputs included the possible water savings for each option in respect to corresponding yield reduction. Database and report characterizing possible adaptation measures to climate changes and to the extreme events have been produced for each Case Study area.

2. Methodology

2.1 Tools and databases used for the simulations

The model used to estimate crop water and irrigation requirements and yield response to different water regimes is the so-called Excel_IRR (Todorovic, 2006) modified within the project to take into consideration the impact of CC (as it was described in D4.4.1 and D4.4.2). Accordingly, the Excel databases have been developed for each CS area and different management strategies.

Crop development is simulated using the heat units concept and the accumulation of growing degree days. The model estimates reference evapotranspiration by five different methods and, for different irrigation practices and scheduling options, determines crop evapotranspiration, irrigation water requirements and eventual yield reduction under non-optimal water supply through the standard procedure proposed by the FAO Irrigation and Drainage 56 Technical document (Allen et al., 1998), and similarly developed in the CROPWAT computer program for irrigation planning and management developed by FAO (Smith, 1992).

2.2 Adaptation 1: Sowing/planting date (field crops, vegetables and olive trees)

Early planting of crops (especially the spring-summer ones) helps to avoid plant drought (and heat) stress during the hotter and drier summer months predicted under climate change. For each location, a relatively wide interval of "effective" planting dates and growing cycles have been considered, through a "shifting" of the optimal average sowing/planting periods (as indicated by local partners), by both "advancing" and "delaying" the extremes of the interval, as reported in Table 1. In the case of olive, the starting of the cropping cycle has been taken as "fixed" (1^{st} of March) for all climate scenarios, because of the difficulties to simulate bud-break (considered as the annual re-start of the vegetative period) with available data.

Table 1 – Sowing/planting periods tested for crop simulation.

Crop	Tested sowing/planting periods
Wheat	From 01/10 to 01/02
Tomato	From 01/03 to 01/05
Potato	From 01/10 to 01/03
Maize	From 15/03 to 15/05
Olive	From 01/03 to 30/11

2.3 Adaptation 2: Variety selection (slower maturing varieties)

As previously mentioned (see Deliverable 4.4.2), a crop growth model based on the "growing degree days" (GDD) approach has been used to compute the length of the stages for a given variety type and under the average monthly thermal conditions of given climate scenarios. The model has been applied also to evaluate the **shortening of the growing cycle** duration under "future" scenarios (with respect to the "present" one) due to the increase of air temperature and GDD accumulation for each crop. As a consequence, a reduction in crop evapotranspiration and yield is expected, due to the shorter available time for biomass accumulation and the reduction in plant transpiration (Wheeler et al. 2000).

In the case of field crops, **slower-maturing (late) varieties** are then suggested to counterbalance the reduction of potential crop yield. To simulate the behaviour of 'new' adapted genotypes under "future" climate conditions, the basic GDD values have been increased by 10%, while the duration of the singular stages have been maintained in similar proportion to those defined for the original variety.

2.4. Adaptation 3: Irrigation scheduling strategies

The effect of different irrigation strategies on yield has been also considered. More specifically, the application of **deficit irrigation (*DI*)** strategy has been evaluated in order to reduce crop water consumption and to counterbalance the expected increase of daily ETc due to climate change. *DI* is an effective management strategy under conditions of water scarcity for increasing water productivity for various crops without causing severe yield reduction, by limiting water applications to drought-sensitive growth stages, and thus improving water use efficiency (Pereira et al., 2002). With the "full irrigation" strategy, a crop is kept at maximum potential *ETc* and no reduction in yield is expected. On the contrary, with *DI* strategy crop *ETc* is fully satisfied only during the selected drought-sensitive stages, otherwise a certain level of water stress is allowed. As a consequence, yield reduction is expected, and its level will depend on the crop *Ky* values for the given stage and the severity of *ETc* reduction. The most appropriate DI strategies have been selected also according to current scientific knowledge on water productivity *WP* (or *WUE*) and crop sensitivity to water stress (Bouman, 2007; Doorenbos and Kassam, 1979; Katerji et al., 2008; Steduto et al., 2007; Steduto et al., 2012; Vaux and Pruitt, 1983)

To simulate the effect of different irrigation strategies on crop water requirements and yield response to water under different climate scenarios, a combination of **7 irrigation strategies** has been then defined and used to run the model for all selected crops as summarized in Table 2.

Table 2 – Irrigation strategies tested with the model to simulate different levels of crop water stress and yield response.

Irrigation strategies	*Management allowable depletion (MAD)*	*Irrigation application coefficient (Kia)*	*Mild water stress*	*Severe water stress*
Full irrigation	*p* – 0.05	0.7	No water; stress allowed	
Mild stress 1	p + 0.10	0.5	Allowed in less sensitive stages	No
Mild stress 2	p – 0.05	0.35	Allowed in all stages	No
Medium stress 2	p + 0.10	0.25	Allowed in very sensitive stages	Allowed in less sensitive stages
Severe stress 1	p + 0.15	0.5	Allowed in very sensitive stages	Allowed in less sensitive stages
Severe stress 2	p + 0.15	0.25	Progressive severe stress allowed in all stages	
Rainfed	1	0	Severe stress allowed in all stages	

2.5 Simulated scenarios for case-study areas

The scenarios simulated for each case study area included a combination of different crops, climatic conditions and management adaptation strategies. A synthesis of simulated scenarios is given schematically in Table 3.

Table 1 – Combination of crop type, climate scenario and adaptation strategies tested for each case study area.

Case study area	Crop	Climate scenario			Adaptation strategies		
		2000	2050	2050+1 (extreme events)	Shifting sowing date	Slow maturing variety selection	Deficit irrigation
Jordan river basin (Jordan)	Wheat	X	X	X	X	X	X
	Tomato	X	X		X	X	X
	Potato	X	X		X	X	X
	Olive	X	X	X			X
Merguellil catchment (Tunisia)	Wheat	X	X	X	X	X	X
	Tomato	X	X		X	X	X
	Potato	X	X		X	X	X
	Olive	X	X	X			X
Nile Delta, Rosetta (Egypt)	Wheat	X	X	X	X	X	X
	Tomato	X	X		X	X	X
	Potato	X	X		X	X	X
	Maize	X	X		X	X	X
Syros Island (Greece)	Wheat	X	X	X	X	X	X
	Tomato	X	X		X	X	X
	Potato	X	X		X	X	X
	Olive	X	X	X			X
Sardinia Region (Italy)	Wheat	X	X	X	X	X	X
	Tomato	X	X		X	X	X
	Maize	X	X		X	X	X
	Olive	X	X	X			X

3. RESULTS

The effectiveness of the selected adaptation strategies have been analyzed and a synthesis of results (presented in details in D4.4.2) is reported in Tables 4, 5, 6, 7 and 8 for Jordan Valley, Merguellil, Rosetta, Syros and Sardinia, respectively. The following general observations on the expected effectiveness, together with some potential limitations, of those strategies can be summarized as:

a) the **shifting of sowing/planting date**, an earlier sowing for winter-spring crops (i.e. wheat, potato) is normally effective in reducing the maximum crop evapotranspiration and coinciding the cropping cycle with the precipitation season. For spring-sown crops (i.e. tomato, maize), the anticipation of sowing/planting date is similarly effective in partially coinciding the growing cycle with the rainy season while keeping ETc and yield in the same range as in 2000. Moreover, it could help in avoiding the exposition to higher daily evapotranspiration rates and decrease the risks of heat and drought stresses during the flowering and yield formation phases. The opposite effects could be obtained when keeping the sowing/planting dates unchanged.

b) the **use of slower maturing varieties** keeping the sowing/planting dates unchanged allows total or partial recovery of the crop cycle length, and is normally effective in increasing the yield to the same levels (or sometimes above) as for “2000” scenario. However, it has some important limitations:

    - increase of crop evapotranspiration and irrigation requirements is observed frequently, so the use of longer maturing varieties in warmer and drier conditions will fail if not supported adequately with irrigation;

    - in Southern Mediterranean sites, farmers already plant varieties with maturity times in the upper range of those available (together with low vernalization requirements); thus, effective adaptation might not be possible without further breeding programs, a process that normally take a decade or longer before newly adapted cultivars are distributed to farmers (Rosenzweig and Tubiello, 2007);

c) **deficit irrigation (DI) strategies** allow to control the level of effective evapotranspiration and net irrigation requirements while achieving satisfactory yield. However, this strategy should be applied only when water availability is limited, a common condition of the Mediterranean environments. The following general recommendations should be pursued:

    - the most appropriate DI strategy should be selected by considering the maximum level of water stress tolerable by each crop, and thus a better technical and scientific knowledge on crop yield response to water and abiotic stresses is required (Jacobsen et al., 2012);

    - the optimal combination of other adaptation strategies has to be selected according to the corresponding cropping pattern, total available water for irrigation and maximum irrigation delivery rate that can be ensured during the cropping cycle;

d) Finally, it should be pointed out that all the above mentioned adaptation strategies might provide responses to climate change associated with smooth changes in mean variables, such as temperature and precipitation regimes (as simulated in this work), but they might be less effective to cope with the expected changes in the climate variability and extreme weather events (such the increased frequency of heat waves and/or heavy precipitation events). As opposed to adaptation to changes in mean conditions which require adjustments in agronomic techniques (e.g. planting calendars, variety types, input amounts), adaptation to future changes in climate variability may require a further attention to stability and resilience of production, rather than an improvement of its absolute levels (Rosenzweig and Tubiello, 2007). On the other side, the simulation of the impact of climate variability on crop yield requires a more complex modeling approach, which is still under further scientific development (Wheeler et al., 2000; Porter and Semenov, 2005; Moriondo et al., 2011).

3.1 Jordan Valley, Jordan

Table 4. The effectiveness and limitations of selected adaptation strategies to cope with expected climate change impacts in Jordan river basin (Jordan).

Crop	Expected climate change impacts (2050)	Use of late maturing varieties (LMV)	Shifting sowing/planting date	Deficit irrigation (*DI*) strategy	Suggested combination of adaptation strategies
Wheat	Reduction in cycle length, *ETc* (-8.6%) and in maximum *Y* (-6.5%)	The use of LMV allows a total recovery of crop cycle length and increase in average *Y* (+5%), but together with an increase in *ETc* (+4.4%) and *NIR* (+8%).	Early sowing date (November) is effective to both control (reduce) *ETc_max* and maximize the effective rainfall pattern.	In combination with the selection of a LMV, under "severe"-type *DI* strategies, *ETc* and *NIR* are projected to increase only slightly with respect to current one.	The use of best adapted LMV, in combination with early sowing (November) and supplemental irrigation (about 150-250 mm of *NIR*), seems effective to ensure a projected *Y* of 3-4 t/ha
Tomato	Reduction in cycle length, *ETc* (-6.4%) and in maximum *Y* (-6.8%)	The use of LMV allows only a partial recovery of crop cycle length (especially for early plantings), and a slight increase in average *Y* (+1.3%), but together with a slight increase in *ETc* (+1.1%) and *NIR* (+2%).	Late sowing date (April) allows an important reduction of *ETc_max*. The higher rainfall pattern is observed with early planting dates (February), but in any case with very low values.	In combination with the selection of a LMV, "medium" to "mild" type of *DI* strategies seems to be effective in ensuring *Y* above the current average national statistical value (about 43 t/ha).	The use of best adapted LMV, together with early sowing and/or a "medium" to "mild" *DI* strategy (480-580 mm of *NIR)*, are expected to ensure a relative high level of *Y* (50-63 t/ha).
Potato	Reduction in cycle length, *ETc* (-9.8%) and in maximum *Y* (-10.3%)	The use of LMV allows a partial recovery of current cycle length, with still a slight decrease, especially for early planting; at the same time, *ETc is* quite all recovered (-0.8%), as well as *Y* level (-0.7%) with respect to "2000".	Early sowing dates (November- December) seems to be effective in increasing *ETc* (in order to recover *Y* level) together with the use of the best rainfall pattern	In combination with the selection of a LMV, "mild" type of *DI* strategies seems to be effective in ensuring *Y* above the current average national statistical value (about 27.5 t/ha).	The use of best adapted LMV with early sowing (Nov.) and/or a "mild" *DI* strategy (450-500 mm of *NIR)*, project a relative stability level of *Y* (27-30 t/ha) with respect to current average national one (27.5 t/ha)

3.2 Merguellil catchment, Tunisia

Table 5. The effectiveness and limitations of selected adaptation strategies to cope with expected climate change impacts in Merguellil catchment.

Crop	Expected climate change impacts (2050)	Use of late maturing varieties (LMV)	Shifting sowing/planting date	Deficit irrigation (*DI*) strategy	Suggested combination of adaptation strategies
Wheat	Reduction in cycle length, *ETc* (-7.8%) and in average *Y* (-8.4%)	The use of LMV allows a total recovery of crop cycle length and increase in average *Y* (+0.9%), but together with an increase in *ETc* (+1.5%) and *NIR* (+7.2%) with respect to "2000".	Early sowing date (November) is effective to both control (reduce) *ETc_max* at the level of "2000", together with the use of the best rainfall pattern.	In combination with the selection of a LMV, under "medium" to "severe" type of *DI* strategies, *ETc* and *NIR* are projected to be on the same level as "2000" ones.	The use of best adapted LMV, in combination with early sowing (November) and supplemental irrigation (about 250-300 mm of *NIR*), seems effective to ensure a projected *Y* of 4.4-4.6 t/ha
Tomato	Reduction in cycle length, *ETc* (-4.6%) and in average *Y* (-3.6%)	The use of LMV allows a partial recovery of crop cycle length and a slight increase in average *Y* (+1.1%), but together with a slight increase in *ETc* (+2.1%) and *NIR* (+5.8%).	Late planting date (April) allows an important reduction of *ETc_max*. On the other side, the higher rainfall pattern is observed with early planting dates (February).	In combination with the selection of a LMV, "medium" to "mild" type of *DI* strategies seems to be still effective in ensuring average *Y* above the current average national statistical value (about 32 t/ha).	The use of best adapted LMV, together with early sowing (February) and/or a "medium" to "mild" *DI* strategy (550-600 mm of *NIR)*, are expected to ensure relatively high levels of *Y* (54-60 t/ha)
Potato	Reduction in cycle length, *ETc* (-7.4%) and in average *Y* (-5.5%)	The use of LMV ensures quite always the complete recovery of current cycle length, with a slight decrease for early planting; *ETc could* slightly increase (+1.1%), together with *NIR* (+4.7%), as well as average *Y* level (+1.2%).	Delaying of planting dates seems to be less effective in increasing *ETc* (in order to recover *Y* level), but the best rainfall pattern is observed under early plantings	In combination with the selection of a LMV, "severe" to "medium" type of *DI* strategies seems to be still effective in ensuring average *Y* above the current average national statistical value (about 15 t/ha).	The use of best adapted LMV, together with early sowing (November) and/or a "mild" *DI* strategy (400-500 mm of *NIR)*, are expected to ensure relatively high levels of *Y* (25-30 t/ha)

3.3 Rosetta, Nile Delta, Egypt

Table 6. The effectiveness and limitations of selected adaptation strategies to cope with expected climate change impacts in Nile Delta, Rosetta (Egypt).

Crop	Main projected climate change impacts (2050)	Use of late maturing varieties (LMV)	Shifting sowing/planting date	Deficit irrigation (*DI*) strategy	Optimal suggested combination of adaptation strategies
Wheat	Reduction in cycle length, *ETc* (-5.2%) and in maximum *Y* (-5.1%)	The use of LMV allows a total recovery of crop cycle length and increase in average *Y* (+3.9%), but together with an increase in *ETc* (+5.2%) and *NIR* (+7.3%).	Early sowing date (November) is effective to both control (reduce) *ETc_max* and optimal effective rainfall pattern (though irrelevant because of the very low rainfall values)	In combination with the selection of a LMV, under "severe"-type *DI* strategies (300-400 mm), *ETc* and *NIR* could increase slightly, but with a corresponding increase in average *Y*.	The use of best adapted LMV, in combination with early sowing (November) and supplemental irrigation (about 250-300 mm of *NIR*), seems effective to ensure a projected *Y* of 3.4-3.9 t/ha
Tomato	Reduction in cycle length, *ETc* (-5.4%) and in average *Y* (-4.5%)	The use of LMV allows a recovery of crop cycle length under most planting dates, with an increase in average *Y* (+2.3%), but with increase in *ETc* (+2.2%) and *NIR* (+2.3%).	Early planting date (February) allows a significant increase of *ETc_max*, together with a relative increase in *Y*. The rainfall patterns variations are not irrelevant.	A combination of a LMV with "medium" to "mild" type of *DI* strategies seems to be still effective in ensuring average *Y* above the current average national statistical value (about 32 t/ha).	The use of best adapted LMV, together with early sowing (February) and/or a "mild" to "medium" *DI* strategy (480-520 mm of *NIR)*, could ensure relatively high level of *Y* (about 46-50 t/ha)
Potato	Reduction in cycle length, *ETc* (-9.5%) and in average *Y* (-9.2%)	The use of LMV ensures the complete recovery of current cycle length, but with a slight decrease for early planting; at the same time, *ETc* slightly increases (+0.7%), together with *NIR* (+3.1%), as well as average *Y* level (+0.4%).	Delaying of planting dates seems to be effective in increasing *ETc* (in order to recover *Y* level). Again, the best rainfall pattern (but with very low values) is observed under early plantings.	In combination with the selection of a LMV, "medium" to "mild" type of *DI* strategies seems to be still effective in ensuring average *Y* above the current average national statistical value (about 22.3 t/ha).	The use of best adapted LMV, together with early sowing (November) and/or a "mild" *DI* strategy (350-400 mm of *NIR)*, are expected to ensure relatively high levels of *Y* (24-26 t/ha)

3.4 Syros Island, Greece

Table 7. The effectiveness and limitations of selected adaptation strategies to cope with expected climate change impacts in Syros Island (Greece).

Crop	Main projected climate change impacts (2050)	Use of late maturing varieties (LMV)	Shifting sowing/planting date	Deficit irrigation (*DI*) strategy	Optimal suggested combination of adaptation strategies
Wheat	Reduction in cycle length, *ETc* (-7.5%) and in maximum *Y* (-8.8%)	The use of LMV allows a total recovery of crop cycle length and increase in average *Y* (+9.5%), but together with an increase in *ETc* (+0.9%) and *NIR* (+15.6%).	Early sowing date (November) is effective to both control (reduce) *ETc_max* and maximize the effective rainfall pattern, but together with a reduction in average *Y*.	Under supplemental irrigation strategies (100-200 mm of NIR), could be expected an increase in average *Y*, above the current average national statistical value (about 2.5 t/ha).	The use of best adapted LMV, in combination with early sowing (November) and supplemental irrigation (100-150 mm of *NIR*), seems to be effective to ensure a projected *Y* of 3.2-4.1 t/ha
Tomato	Reduction in cycle length, *ETc* (-5.6%) and in average *Y* (-5.9%)	The use of LMV allows a recovery of crop cycle length under most planting dates, with an increase in average *Y* (+1.8%), but together with a an increase in *ETc* (+2.4%) and *NIR* (+3.3%).	Early planting dates (March) allows a significant increase of *ETc_max*, together with a relative increase in *Y*, and the rainfall patterns are more favorable, although still with very low values.	Selection of a LMV with a “medium” to “mild” *DI* seems to be still effective in ensuring average *Y* at the level of the current average national statistical value (about 46.8 t/ha).	The use of best adapted LMV, together with early sowing (March) and/or a “medium” to “mild” *DI* strategy (380-450 mm of *NIR)*, are expected to ensure relatively high levels of *Y* (about 45-58 t/ha).
Potato	Reduction in cycle length, *ETc* (-8.3%) and in average *Y* (-7.9%)	LMV ensures quite always the complete recovery of current cycle length, but with still a slight decrease for early planting; at the same time, *ETc* slightly increases (+0.3%), together with *NIR* (+7.8%), but the effect on *Y* depends on the irrigation level.	Delaying of planting dates seems to be less effective in increasing *ETc* (in order to recover *Y* level), but the best rainfall pattern is observed under early plantings (November-December).	In combination with the selection of a LMV, a slightly “severe” to “medium” type of *DI* strategies seems to be still effective in ensuring average *Y* above the current average national statistical value (about 20.4 t/ha).	The use of best adapted LMV, together with early sowing (November-December) and/or a “medium” *DI* strategy (250-300 mm of *NIR)*, are expected to ensure relatively high levels of *Y* (27-28 t/ha)

3.5 Sardinia region, Italy

Table 8. The effectiveness and limitations of selected adaptation strategies to cope with expected climate change impacts in Sardinia region (Italy).

Crop	Main projected climate change impacts (2050)	Use of late maturing varieties (LMV)	Shifting sowing/planting date	Deficit irrigation (*DI*) strategy	Optimal suggested combination of adaptation strategies
Wheat	Reduction in cycle length, *ETc* (-6.5%) and in average *Y* (-6.4%)	LMV allows a total recovery of crop cycle length and increase in average *Y* (+2.5%) (although depending on the irrigation level), but together with an increase in *ETc* (+3.2%) and *NIR* (+16.9%).	Early sowing date (November) is effective to both control (reduce) *ETc_max* and maximize the effective rainfall pattern, but together with a reduction in average *Y*.	With rainfed or supplemental irrigation (50-100 mm), a corresponding increase in average *Y* is expected, above the current average national statistical value (3.3 t/ha).	Best adapted LMV, in combination with early sowing (November) and supplemental irrigation (50-100 mm of *NIR*), seems to be still effective to ensure a *Y* of 5.7-6.2 t/ha
Tomato	Reduction in cycle length, *ETc* (-5.8%) and in average *Y* (-6%)	The use of LMV allows only a partial recovery of crop cycle length under most planting dates, with a slight increase in average *Y* (+0.3%), but together with a an increase in *ETc* (+1.1%) and *NIR* (+4.8%).	Late planting dates (May) allows a significant decrease of *ETc_max*, but together with a relative decrease in *Y*, while the rainfall patterns are more favorable with earlier plantings.	In combination with the selection of a LMV, a "medium" to "mild" type of *DI* strategies seems to be still effective in ensuring average *Y* at the level of the current average national statistical value (about 50 t/ha).	The use of best adapted LMV, together with early sowing (March) and/or a "medium" to "mild" *DI* strategy (400-420 mm of *NIR)*, are expected to ensure relatively high levels of *Y* (about 60 t/ha).
Maize	Reduction in cycle length, *ETc* (-5.1%) and in average *Y* (-5.9%)	LMV allows only a partial recovery of cycle length, with a slight decrease for early planting; at the same time, *ETc* increases slightly (+1.7%), together with *NIR* (+5.2%), and with Y (+3.2%).	Late planting dates (May) allows a significant decrease of *ETc_max*, but together with a relative decrease in *Y*, while the rainfall patterns are more favorable with earlier plantings.	LMV In combination with "mild" DI to "full" irrigation seems to be effective in ensuring average *Y* above the current average national statistical value (about 8.9 t/ha).	The use of best adapted LMV, together with early sowing (March) and/or a "mild" *DI* strategy (480-530 mm of *NIR)*, are expected to ensure relatively high levels of *Y* (9.4-10.4 t/ha).

4. Conclusions

Agricultural production in the Mediterranean strongly relies on climate. Both crop water requirements and yields vary from year to year depending on climate variability and the period of growing during the year. In general, the impact of CC in the future will likely be related to the local climatic conditions and could be prevalently: i) positive for the Northern Mediterranean countries and areas characterized by relatively cold and humid climate, and ii) negative for the Southern Mediterranean countries and the areas already characterized by arid and semi-arid conditions.

The main effect of temperature rise under future climate scenarios (2050) would be:

- the **extension of the areas suitable for cultivation** to the lands where actual weather is too cold, i.e. shifting of areas suitable for cultivation toward the Northern latitudes and higher altitudes (especially valid for the Northern Mediterranean);
- the **extension of the season suitable for cultivation**, especially important for the Northern Mediterranean countries.
- the **shortening of the growing cycle** (provided that the start of the growing season will not change) for all annual crops examined, in general and in the CS areas.
- **Spontaneous adaptation** to CC through the **anticipation of the sowing/planting dates** for spring-summer crops which will **increase the frost risks** in the Northern Mediterranean countries and will **reduce** the interception of photo-synthetically active radiation (**PAR**) in all areas with a negative effects on yield.

Accordingly, at the regional scale:

- The average length of growing cycle of annual crops is likely to be shorter in 2050 over the whole Mediterranean by 15, 13, 12 and 9 days for winter wheat, maize, tomato and sunflower, respectively. Therefore, potential impact of climate change on annual crops would be mainly from the air temperature rise that could strongly affect crop development. In fact, the shortening of the growing season could reduce the amount of intercepted photo-synthetically active radiation that could cause the reduction of production. However, it could be expected that an increase of CO_2 concentration might alleviate this negative impact especially in the case of C3 crops (Kimball et al., 2002; Ainsworth and Long, 2005; Giannakopoulos *et al.*, 2009; Pereira, 2011).

- Due to shorter growing season, the average crop ET over the whole region is expected to decrease by 8% and 4% for winter wheat and maize, respectively, while 5% decrease is expected for sunflower and tomato. The average NIR would decrease by 12% for winter wheat, 7% for sunflower and tomato; while for maize decrease of NIR would be 4%. These results can be explained by an overall reduction of crop ET as well as the spatial and temporal variability of the precipitation change.

- In general, a decrease of crop ET and NIR for most crops (except olive trees) could be expected due to reduction of growing season. Therefore, the air temperature increase could have a dominant role on the shortening of the growing season rather than on the increase of CWR.

- The impact of precipitation decrease would be limited only to the perennial and winter crops because that most of spring-summer agricultural production in the Mediterranean is already characterized by very low rainfall input. However, the results depend on the adopted SRES scenario and upon the application of global and regional climate models that generate weather data.

For CS areas selected in the Mediterranean basin, the overall response depends significantly on the limiting factors, mainly water and nutrient. It could be expected that the disadvantages due to climate change will predominate because of lower harvestable yields, higher yield variability and a reduction of suitable areas for traditional crops. Furthermore, the production might be negatively affected by an increase in the frequency of extreme events. The effects of adaptation measure should consider the adaptation capacity of each specific area and could have greater success in the Northern than in the Southern Mediterranean countries. Hence, on the basis of simulations of different adaptation strategies in CS areas, the following further conclusions can be reported:

a) In most cases, the reduction of the growing cycle length and the shifting of the *Kc* curve, will determine a **reduction in the maximum seasonal crop evapotranspiration**, and thus of the total annual crop water requirements.
b) As a consequence, also the seasonal **effective crop evapotranspiration and net irrigation requirements are expected to decrease** in 2050, but the relative percentages of reduction depend mostly on the specific case study area and adopted irrigation strategy.
c) On the other side, **peak ETc** estimated on a shorter time scale (daily, weekly or monthly) **is expected to increase**, thus determining a **higher rate of crop water requirements and irrigation supply** (higher frequency or amount of irrigation water needed, although the total seasonal water requirements will be lower).
d) The shortening of the growing period will result in **lower seasonal crop (evapo)transpiration** and **reduced interception of PAR** and, then, in a shorter development period, reduced yield formation phase and crop grow rate (of biomass accumulation), and thus in the **reduction of crop yield**. These changes in yield will depend on crop phenology (e.g. spring-summer and winter crops), crop type (C3 and C4 plants) and environmental conditions (water availability).
e) Nevertheless, this decline in yield could be effectively countered by the enhancement of the rate of photosynthesis under future conditions of elevated atmospheric CO_2 concentrations. According to our results, if the expected **increase in atmospheric CO_2 concentration** will occur (following the increase rate of 2ppm per year and consequent increase of water productivity by 20%), **yield could increase in quite all conditions** (and especially under optimal water supply), and, thus, overcome the effects of the shortening of the crop growing cycle.
f) Nonetheless (and apart from the CO_2 effect), the reductions in yield of determinate crops due to shorter growing cycle could be countered by **changing to a variety which has the longer growing cycle (and slower yield formation and maturity phase)**, and with different physiological sensitivity to temperature and/or photoperiod. Anyway, this adaptation strategy will determine quite always an **increase in seasonal crop evapotranspiration and net irrigation requirements**. However, a decrease of water availability for irrigation is expected in most of Southern Mediterranean countries.
g) Thus, an effective combination of **planting/sowing date** and **regulated deficit irrigation strategy** could be very helpful in ensuring a satisfactory yield without excessive increase in crop water requirements. Especially in the case of winter-spring crops, the application of appropriate **supplemental irrigation** strategies could contribute to yield stabilisation and increase.
h) In the case of "**extreme weather**" conditions, a further important reduction of the total growing cycle could be expected for quite all planting dates, because of the faster accumulation of the required GDD sum; as a consequence, the reduction in yield will be

more important and grater amount of irrigation water will be needed to avoid huge losses of production.

i) In the "extreme conditions", if a late maturing variety is considered, the total crop cycle length is normally only partly recovered with respect to the baseline scenario. Additionally, an **increase** of both effective **crop evapotranspiration** and (more significantly) of net **irrigation requirements** could be expected. However, under those conditions, the capability of cultivation would be limited in most regions and yield is expected to decrease.

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