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Symbol	Definition	Units
<i>CR</i>	capillary rise from groundwater	mm
<i>CWP</i>	actual “crop water productivity”	kg
<i>DAF</i>	leaf area density of olive tree	m ² m ⁻³
<i>DAS</i>	days after sowing or planting	days
<i>De</i>	water depletion in the effective root zone at the end of each day	kg m ⁻³
<i>DI</i>	deficit irrigation	-
<i>DP</i>	deep percolation	mm
<i>dp</i>	tree density	n. trees per ha
<i>E</i>	soil evaporation	mm
<i>e_a</i>	actual vapour pressure	kPa
<i>e_s</i>	saturation vapour pressure	kPa
<i>ET_{c_eff}</i>	effective crop evapotranspiration	mm
<i>ET_{c_max}</i>	maximum crop evapotranspiration	mm
<i>ET_o</i>	reference evapotranspiration	mm
<i>f_{CO2}</i>	CO ₂ correction coefficient for water productivity	-
<i>Fw (or wz)</i>	fraction of wetted zone by drip emitters	-
<i>F1</i>	empirical parameter	-
<i>G</i>	soil heat flux	MJ m ⁻² day ⁻¹
<i>GC</i>	fraction of ground cover	-
<i>GDD</i>	growing degree days	°C
<i>HU</i>	heat units	°C
<i>IR</i>	irrigation amount	mm
<i>Kc</i>	crop evapotranspiration coefficient	-
<i>K_{c,c}</i>	transpiration component of the cover crops and weeds of <i>Kc</i>	-
<i>K_{c,Tr}</i>	transpiration component of <i>Kc</i>	-
<i>k_{est}</i>	coefficient for tree radiation attenuation	-
<i>K_{dz}</i>	evaporation component from the wetted fraction of the soil of <i>Kc</i>	-
<i>K_{pd}</i>	plant direct evaporation of <i>Kc</i>	-
<i>Ks</i>	water stress coefficient	-
<i>K_{wz}</i>	general soil evaporation component of <i>Kc</i>	-

K_y	yield response to water factor	-
L	duration of main crop growth stages	days
MAD	management allowable depletion	-
NIR	net irrigation requirement	mm
p	depletion fraction threshold for optimum yield	-
P	rainfall	mm
Q_d	fraction intercepted radiation by tree	-
RAW	readily available soil water	mm
R_d	rooting depth	m
R_n	surface net radiation	MJ m ⁻² day ⁻¹
RO	surface runoff	mm
T	average air temperature at 2 m height	°C
T_{avg}	average air temperature	°C
T_b	crop base temperature	°C
T_{co}	crop cut-off temperature	°C
T_r	crop transpiration	mm
T_{max}	maximum air temperature	°C
T_{min}	minimum air temperature	°C
TAW	total available water	mm
u_2	wind velocity at 2 m	m s ⁻¹
V_o	tree canopy volume	m ³
V_u	tree canopy volume per unit area	m ³ m ⁻²
WP	water productivity	kg m ⁻³
WP_{adj}	adjusted water productivity	kg m ⁻³
wz (or F_w)	fraction of wetted zone by drip emitters	-
Y	crop yield	t ha ⁻¹
Y_a	actual crop yield under water stress	t ha ⁻¹
Y_m	maximum crop yield without water stress	t ha ⁻¹
YR	relative yield or percentage of yield (with respect to Y_m)	%
γ	psychrometric constant	kPa °C ⁻¹
Δ	slope of the saturation vapour pressure curve	kPa °C ⁻¹
θ_{FC}	water content at field capacity	m ³ m ⁻³
θ_{WP}	water content at wilting point	m ³ m ⁻³

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1. Introduction

The document has been produced as a result of the activities of T4.4.2 of the project aiming at the assessment of possible adaptation measures to climate change (CC) and to the extreme events. 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 2010 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 Irrigatio 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 T4.1. 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. A 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. Brief description of the model

2.1.1. Basic model for crop-soil water balance (FAO 56 approach)

The model used to estimate crop water and irrigation requirements is the so-called *Excel_IRR* (Todorovic, 2006) modified to take into consideration the impact of CC (as it has been mentioned in D4.4.1). Crop development is simulated using the heat units concept and the accumulation of growing degree days. For different irrigation practices and scheduling options, the model estimates irrigation water requirements, crop evapotranspiration and yield reduction 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).

Model input **weather data** include location information (name, altitude, latitude and sensors height) and daily values of weather variables (precipitation, minimum and maximum temperature and relative humidity, windspeed and incoming solar radiation or number of sunshine hours). The software *Excel_IRR* provides the default values of some basic parameters for estimate of reference evapotranspiration (albedo, Angstrom coefficients, coefficient of Hargreaves, equation and coefficient for the adjustment of solar radiation) and allows for their modification when necessary. All parameters and intermediate steps are calculated as described in Allen et al. (1998).

Then, the software estimates reference evapotranspiration (ET_o) by the standard **FAO Penman-Monteith approach**, provided that a complete set of weather data is available. The formulation of the Penman - Monteith equation is the following (Allen et al., 1998):

$$ET_o = \frac{0.408 \Delta (R_n - G) + \gamma \frac{900}{T + 273} u_2 (e_s - e_a)}{\Delta + \gamma (1 + 0.34 u_2)} \text{ (mm day}^{-1}\text{)}$$

Where ET_o (mm day⁻¹) is the reference evapotranspiration, Δ (kPa °C⁻¹) is the slope of the saturation vapour pressure curve, R_n (MJ m⁻² day⁻¹) is the surface net radiation, G (MJ m⁻² day⁻¹) is the soil heat flux, T (°C) is the average air temperature at 2 m height, u_2 (m s⁻¹) is the wind velocity at 2 m, e_s (kPa) is the saturation vapour pressure, e_a (kPa) is the actual vapour pressure, and γ (kPa °C⁻¹) is the psychrometric constant.

Crop input data are the following: name of crop (and variety); “base” (T_b) and “cut-off” (T_{co}) temperatures, if the simulation of crop development is based on the “growing degree day” method; initial and maximum root depth; length (L) of duration of four main crop growth stages (initial, development, mid season and late season) together with corresponding values of crop coefficient (K_c), yield reduction coefficient (K_y), and depletion fraction threshold for optimum yield (p).

The total cropping cycle is subdivided in four stages: i) the “initial stage” runs from planting date to approximately 10% ground cover; ii) the “crop development stage” runs from 10% ground cover to

effective full cover; (effective full cover for many crops occurs at the initiation of flowering); iii) the “mid-season stage” runs from effective full cover to the start of maturity (the start of maturity is often indicated by the beginning of the ageing, yellowing or senescence of leaves, leaf drop, or the browning of fruit); iv) the “late season” stage runs from the start of maturity to harvest or full senescence. The length of the growing stages can be either selected from literature or computed according to the growing degree days method.

The length of the growing stages depends mainly on variety and climatic conditions, first of all temperature. A linear crop development function, based on the “**growing degree days**” (*GDD*) or “heat units” (HU) approach (Bonhomme, 2000), has been used to compute the length of the stages for a given variety type and under the average daily thermal conditions of climate scenarios. Two alternative methods are currently used for the computation of daily *GDD* (Raes *et al.* 2009; McMaster and Wilhelm 1997). According to the so-called “**method 1**”, daily *GDD* is computed as the sum of average air temperatures that are greater than a crop specific ‘base’ temperature (T_b) and lower than a maximum or “cut-off” temperature (T_{co}). In mathematical terms:

$$GDD = \begin{cases} T_{avg} - T_b, & \text{if } T_{avg} < T_{co} \\ T_{co} - T_b, & \text{if } T_{avg} \geq T_{co} \\ 0, & \text{if } T_{avg} \leq T_b \end{cases}$$

and where:

$$T_{avg} = (T_{max} + T_{min})/2$$

where T_{avg} , T_{max} and T_{min} are respectively the average, maximum and minimum daily temperature. The comparison to T_b and T_{co} occurs after the calculation of T_{avg} . This method has been applied as the standard one.

As an alternative, in the “**method 2**” this comparison occurs before, and T_{max} and T_{min} are adjusted as follows:

$$T'_{max} = \begin{cases} = T_{max} & \text{if } T_{max} < T_{co} \\ = T_{co} & \text{if } T_{max} \geq T_{co} \end{cases}$$

and

$$T'_{min} = \begin{cases} = T_{min} & \text{if } T_{min} < T_b \\ = T_b & \text{if } T_{min} \geq T_b \end{cases}$$

so

$$T_{avg} = (T'_{max} + T'_{min})/2$$

and finally, *GDD* are again computed as mentioned above. With method 2, the relative effect of daily maximum (and minimum) temperature is considered in terms of the slowing of *GDD* accumulation (and thus of the developmental rate) that is limited by the cut-off value. For our purposes, this method has been applied in combination with the “extreme weather” climate scenario (2050+1) (see next par. 2.2.1.).

The *GDD* model has been applied to predict the variation of available heat units by using available daily average temperatures, and consequently to estimate the changes in the cropping season duration and crop coefficient curves under different climate conditions (fig.1). Once the length of

stages and the values of K_c have been specified, the daily **maximum crop evapotranspiration** (ET_{c_max}) is calculated as:

$$ET_{c_max} = K_c ET_c$$

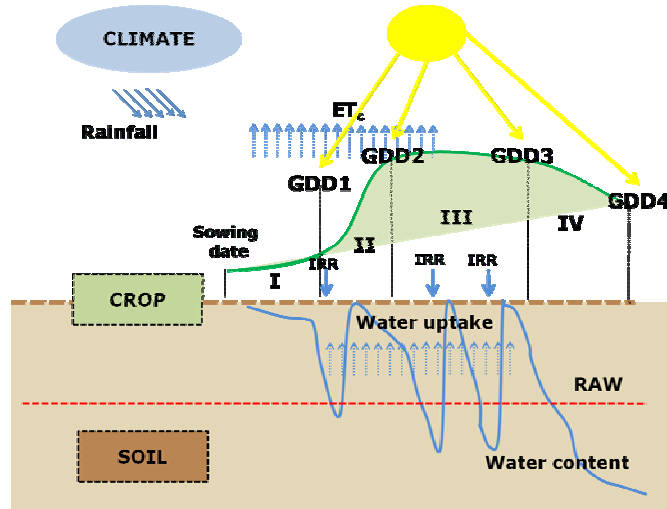


Fig. 1 – Schematic representation of the integration between the crop-soil water balance, the crop coefficient curve and the GDD model.

The **soil water balance module** contains all information related to soil and crop and uses the reference evapotranspiration data estimated in the previous module. Soil has to be characterized by texture, depth, and volumetric water content at field capacity (θ_{FC}) and wilting point (θ_{WP}), and the corresponding soil water holding capacity ($\theta_{FC} - \theta_{WP}$). Total available water (TAW) is then calculated by multiplying the soil water holding capacity by the rooting depth (Rd). Taking into account the specific crop depletion coefficient (p), the readily available water (RAW) is then estimated as:

$$RAW = p \cdot TAW = p \cdot (\theta_{FC} - \theta_{WP}) \cdot Rd$$

Soil water balance is calculated on a daily basis following the scheme illustrated in Figure 2 and it is expressed in terms of water depletion (De) in the effective root zone at the end of each day.

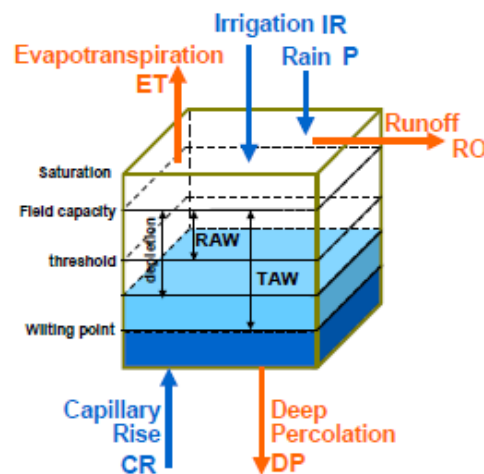


Fig. 2 – Schematic presentation of the soil water balance components (Todorovic, 2006).

Losses and gains of the soil water budget are expressed in terms of water depth. Rainfall (P), irrigation (IR) and capillary rise of groundwater (CR) add water to the root zone and decrease the root zone depletion. Soil evaporation (E), crop transpiration (T) and percolation losses (DP) remove water from the root zone and increase the depletion. For our purposes, capillary rise and runoff (RO) have been considered to be negligible.

The **irrigation module** uses net irrigation supply determined in the soil water balance module and calculates gross irrigation volume considering the efficiency of irrigation application, total wetted area and surface area of the field under consideration. To avoid crop water stress, **net irrigation requirement** (NIR) is automatically taken as equal to the root zone depletion, and irrigations is applied before or at the moment when the readily available soil water (RAW) is depleted. In order to simulate different irrigation strategies (full or deficit irrigation) and thus to control the timing and quantity of irrigation to apply, it is possible to modify the following specific parameters of the module: i) the “management allowable depletion” (MAD), a threshold value respectively higher, equal or lower than p , so changing the timing of irrigation; ii) the “irrigation application coefficient” (Kia), which allows to proportionally modify the scheduled quantity of water to apply at any irrigation event.

Under water stress conditions ($De > RAW$), ET_c is proportionally reduced (the so-called **effective crop evapotranspiration**, ET_{c_eff}) as follows:

$$ET_{c_eff} = K_s ET_{max} = K_s K_c ET_c$$

where K_s (≤ 1) is a water stress coefficient, dependent on available soil water in the root zone (Allen *et al.*, 1998):

$$K_s = \frac{(TAW - De)}{(TAW - RAW)}$$

K_s coefficient allows to describe the effect of soil water deficit on crop evapotranspiration, which is assumed to decrease linearly in proportion to the reduction of water available in the root zone.

The basic **outputs** of the model include the seasonal values of crop water requirements, effective evapotranspiration, net irrigation, effective rainfall, relative yield and number of days under water stress (tab. 1).

Tab. 1 – An example of the main output variables of the model.

Crop	planting date (GDD model)	harvesting date (GDD model)	total length (GDD model)	Irrigation strategy	Relative yield (Rao et al. 1988)	Days under stress	ET _{c_eff} [mm]	ET _{c_max} [mm]	NIR [mm]
Maize	15-May	8-Oct	146	Full	100%	0	641.8	641.9	511.9
Maize	15-May	8-Oct	146	Mild 1	92.84%	41	621.0	641.9	473.1
Maize	15-May	8-Oct	146	Mild 2	70.87%	70	566.4	641.9	409.5
Maize	15-May	8-Oct	146	Medium	72.26%	82	542.9	641.9	397.4
Maize	15-May	8-Oct	146	Severe 1	44.58%	116	471.1	641.9	307.5
Maize	15-May	8-Oct	146	Severe 2	23.42%	132	362.9	641.9	198.7
Maize	15-May	8-Oct	146	Rainfed	0.00%	132	179.0	641.9	0.0

2.1.2. Alternative Kc model for olive crop (FAO 66 approach).

The main problem in simulating the crop evapotranspiration, irrigation requirements and yield response to water for the olive crop (and in general for fruit crops and trees), is the lack of reliable parameters and data to simulate properly crop development and phenology, and more specifically the K_c curve. For this reason, given the above described crop-soil water balance model, some additional assumptions has been taken to simulate the behavior of the olive crop. For the calculation of the length of K_c -stages, a “fixed stage-length” approach has been chosen, by using the standard length duration (30-90-60-90 = 270 total) as suggested by Allen *et al.* (1998), for both “present” and “future” scenarios. Then, for the estimation of proper K_c values, two different approaches have been compared:

i) by considering the average reference monthly K_c values as suggested by Fereres (in Steduto *et al.*, 2012) for both semi-arid environments (in our case for Sardinia Region, Syros Island) and arid environments (Merguellil catchment, Nile Delta, Jordan river basin), and as listed in the Table 2;

Tab. 2 – Parameters of the K_c model for olive crop as suggested by Fereres in Steduto *et al.* (2012)

Climate / Month	1	2	3	4	5	6	7	8	9	10	11	12
Semi-arid envir.	0.75	0.75	0.75	0.65	0.55	0.55	0.55	0.55	0.6	0.65	0.65	0.65
Arid environ.	0.45	0.45	0.45	0.5	0.55	0.55	0.5	0.5	0.6	0.65	0.65	0.65

ii) by calculating the “combined” monthly K_c values through its components, according to the approach developed by Orgaz *et al.* (2006) and Steduto *et al.* (2012), as follows:

$$K_c = K_{c,Tr} + K_{c,c} + K_{wz}(1 - Fw) + K_{dz}Fw + K_{pd}$$

where $K_{c,Tr}$ is the transpiration component, $K_{c,c}$ is the transpiration component of the covering crops and weeds, K_{wz} is the general soil evaporation component, K_{dz} is the evaporation component from the fraction of the soil (Fw or wz) wetted by the emitters (and thus considering a localized irrigation system), K_{pd} is the plant direct evaporation component. Two different olive cropping systems have been considered, an “extensive” (or “old”) and an “intensive” (or “new”) ones, by changing some specific model parameters as reported in Table 3.

Tab. 3 – Parameters of the K_c model for olive crop as suggested by Orgaz *et al.* (2006)

Crop/irrigation parameters	“extensive” (or “old”) cropping system	“intensive” (or “new”) cropping system
Tree density (dp) (trees/ha)	100	300
Tree canopy volume (Vo) (m3/tree)	120	50
Tree canopy volume per unit area (Vu) (m3/m2)	1,2	1,5
Leaf area density (DAF, Ld) (m2/m3)	1,63	1,47
Coefficient for radiation attenuation (k,est)	0,50	0,64
Fraction intercepted radiation (Qd)	0,45	0,61
Empirical parameter (F1)	0,72	0,66
Ground cover fraction (GC)	0,4	0,4
Fraction wetted zone by emitters (Fw; wz)	0.1	0.1

Accordingly, in Table 4 is summarized the combination of “crop models” tested for olive crop.

Tab. 4 – Acronyms of the crop models tested for olive crop.

Crop model (acronyms)	Length of Kc stages	Monthly Kc values
New_orgaz_270	Fixed (270)	Orgaz et al. 2006 applied for “new” crop type
Old_orgaz_270	Fixed (270)	Orgaz et al. 2006 applied for “old” crop type
Standard FAO66	Fixed (270)	Kc values as reported in Steduto et al. (2012) for arid or semiarid environments

2.1.3. Yield response functions and water productivity

Relative yield (YR) reduction due to soil moisture stress is expressed as a percentage of the maximum production achievable in the area under optimal conditions. It can be computed with reference to a single stage of crop cycle or to the whole growing season. The coefficient K_y is a specific yield response factor that describes the reduction in relative yield according to the reduction in relative evapotranspiration. Relative yield due to water stress is generally calculated by using either the standard FAO-56 method based on a single K_y for all the cropping season (Allen et al., 1998) or a more complex and multiplicative approach as described in Rao et al. (1988). The latter has been preferred for this application, and it is based on the following formula:

$$YR = \frac{Y_a}{Y_m} = \prod_{i=1}^N \left[1 - K_{y,i} \left(1 - \frac{ET_{c,eff,i}}{ET_{c,max,i}} \right) \right]$$

Where YR is yield reduction expressed in percentage, Y_a and Y_m are respectively the actual and the maximum expected crop yield with and without water stress, while $ET_{c,eff}$ and $ET_{c,max}$ are daily crop evapotranspiration with and without water stress. K_y values are crop specific and may vary over the growing season. In general, for field crops the decrease in yield due to water deficit during the vegetative and ripening period is relatively small, while during the flowering and yield formation periods is large (Allen, 1998).

To estimate the crop **yield (Y)** in absolute terms ($t\ ha^{-1}$) for each country, under the given climate and management conditions, crop average values of **water productivity (WP, $kg\ m^{-3}$)** have been considered. Maximum (potential) yield (Y_m) has been computed as follows:

$$Y_m = 0.01 \cdot ET_{max} \cdot WP$$

while actual yield (Y_a) as:

$$Y_a = Y_m \cdot YR = 0.01 \cdot ET_{max} \cdot WP \cdot YR$$

In the case of olive trees, because of the lack of reliable K_y coefficients for different development stages, an additional alternative yield response function has been considered, as obtained by Moriana *et al.* (2003) and suggested by Steduto *et al.* (2012):

$$Y_a = -16.84 + 0.63 \cdot ET_c - 0.000035 \cdot ET_c^2$$

In the case of field crops, to consider the expected “fertilizing effect” of increasing CO₂ levels on crop productivity, an **adjusted WP** (WP_{adj}) value has been additionally used under “future” 2050 climate conditions, according to the methodology suggested by Raes *et al.* (2012):

$$WP_{adj} = WP \cdot f_{CO_2}$$

where f_{CO_2} is the correction coefficient, estimated as equal to 1.2 under the conditions of our application.

2.2. Input data and crop parameters

2.2.1. Climate data

Climate data have been developed within WP2 by the CMCC (Euro-Mediterranean Centre for Climate Change) as it was described in WP2 Final Report and D 2.1.4.. The data have been derived from the ENSEMBLES project (EC-FP6-ENV) RCM simulations driven by the General Circulation Model **ECHAM5**. The data refer to **A1B SRES scenario**. **RACMO2** was selected as the most suitable precipitation model for the Mediterranean region and Case Study (CS) areas. In order to estimate uncertainties of model results, the mean and the two “top” and “bottom” cycles of the ENSEMBLES models driven by ECHAM5 have been done to represent the inter-modal spread. Data representing the mean values of simulations done by different models were used which ensure the robustness of the results over the whole Mediterranean area. Spatial resolution of data is approximately 0.25° x 0.25°.

The **climatic databases for the CS areas** considered only the grid of points corresponding geographically to the areas of study and/or those being close to that area. For each of 5 CS areas have been done a separated analysis and elaboration of the climatic data as presented and described in D 4.4.1. The following **climatic variables** were available on a monthly basis: average temperature at 2m height (°C); maximum temperature at 2m height; minimum temperature at 2m height; precipitation (mm/month); average relative humidity (%); maximum relative humidity (%); minimum relative humidity (%); solar (incoming) radiation (W/m²); sunshine duration (hours); wind speed at 10m (m/s), converted to a reference 2m height as described by Allen *et al.* (1998).

The **generation of daily weather data** from the available monthly database was necessary for the completion of soil water balance and irrigation scheduling at different locations. The linear regression was used to generate daily temperature, humidity, solar radiation and wind speed data from available monthly climatic variables. Daily precipitations were generated with a simplified stochastic approach. The number of rainy days was generated as the integer of $(P/10+1)$ where P is monthly precipitation. Maximum number of rainy days was fixed to 28 and adopted for all months when P was greater than 280mm. The rainy days are selected randomly in each month. Consequently, the rainfall amounts on wet days were fixed for each specific month depending on the monthly precipitation and on the number of rainy days.

The **climate scenarios** considered refers to two time periods: i) “**present**”, also called year ‘**2000**’ (average values of simulations for the period 1991-2010), and ii) “**future**”, called year ‘**2050**’ (average values of simulations for the period 2036-2065). An additional climate scenario has been

considered to evaluate the effect of climate extreme on the cropping systems, the called iii) a **future “extreme weather”** (or ‘2050+1’), simulated by adding +1°C to the daily maximum and minimum temperatures and by reducing of -30% the daily rainfall of the “future” scenario daily climate database.

It was difficult to simulate properly the “extreme weather” events (hot spells, erratic rains and long dry periods) due to their variability in time and in intensity from year to year and from place to place. Therefore, an average increase of air temperature by 1°C and the reduction of precipitation by 30% are taken as the reference extreme weather conditions at all sites.

2.2.2. Soil data

To set the parameters of the soil module of the model, soils at all sites have been designated as a **medium loamy textured soil**, with an average depth of 0.90 m and a soil water holding capacity set equal to 135 mm/m, representing moderately productive land capability. No other data were available for CS areas.

2.2.3. Crop data

A selection of the most important crops has been considered for the simulation in each country under study (by also considering the information provided by local project partners about their relative importance for local agriculture), as follows: **wheat** (winter cereal), **maize** (summer cereal), **tomato** (vegetable crop), **potato** (tuber crop), **olive** (tree crop).

Specific **crop parameters** have been selected to run the model in each site. For the crop development model, values of base (T_b) and cut-off (T_{co}) temperatures and GDD requirements for each developmental stage have been chosen, as listed in the following table (Masoni *et al.*, 1990; Narciso *et al.*, 1992; Hsiao *et al.*, 2009).

Tab. 5 – Selected values of T_b , T_{co} and GDD sum required for the simulation of wheat, maize, tomato and potato development.

Crop	T_b	T_{co}	GDD sum (°C)			
			(initial)	(development)	(mid-season)	(late)
Wheat	0	30	250	1250	1900	2500
Tomato	10	35	100	500	900	1200
Potato	6	27	150	550	1200	1600
Maize	8	30	100	650	1300	1600

The most suitable **sowing/planting dates** and the **length of stages** (if not computed with the GDD method) for each site have been selected according according to Allen *et al.* (1998) and eventually adjusted according to information provided by local partners. Also the values of **depletion fraction (p)**, initial and maximum **rooting depth**, have been selected according to those reported in Allen *et al.* (1998).

The selection of the appropriate evapotranspiration **crop coefficients (K_c)** for each crop has been done by considering FAO reference values (Allen *et al.*, 1998) and data provided by local partners.

In Table 6 are reported the K_c values used for simulations. For the olive crop, K_c values have been determined as yet reported in paragraph 2.1.2.

Tab. 6 – Selected values of K_c for the simulation of wheat, maize, tomato and potato K_c -curve.

Crop	K_c <i>initial</i>	K_c <i>mid-season</i>	K_c <i>late</i>
Maize	0.3	1.2	0.35
Wheat	0.7	1.15	0.25
Potato	0.5	1.15	0.75
Tomato	0.6	1.15	0.8

The selection of **K_y coefficients** has been done according to current scientific knowledge based on FAO standards (Allen et al., 1998; Steduto et al., 2012; FAO Water, *online*), as reported in Table 7.

Tab. 7 – Selected values of K_y for the simulation of yield response to water of wheat, maize, tomato, potato and olive.

Crop	K_y <i>initial</i>	K_y <i>development</i>	K_y <i>mid-season</i>	K_y <i>late</i>	K_y <i>total</i>
Maize	0.4	0.4	1.3	0.5	1.25
Wheat	0.2	0.5	0.6	0.3	1.15
Potato	0.45	0.8	0.8	0.3	1.1
Tomato	0.4	0.4	1.1	0.6	1.05
Olive	0.2	0.5*	0.8*	0.5*	1*

*values estimated by the authors

In the specific case of olive crop, because of the lack of reliable K_y values (except for initial stage = 0.2, according to FAO Water, *online*), arbitrary K_y values have been selected by the authors for the development, mid-season and late stages (respectively 0.5-0.8-0.5), to consider the higher water stress sensitivity during the yield formation period (mid-stage of the K_c curve) as suggested by Steduto *et al.* (2012).

In a previous deliverable of the Wasserved project (Deliverable n. 4.1.3.), average values of **actual “crop water productivity” (CWP)** have been calculated as the ratio between average national crop yield (kg ha^{-1}) (official FAO statistics) and crop water requirements estimated (by the model) under current climate conditions ($\text{m}^3 \text{ ha}^{-1}$). These values are far from the “potential” maximum ones, because reported statistical yields are normally obtained as an average of several sub-optimal cropping systems and management conditions. Anyway, the comparison of CWP values is useful to have an idea of the different “productivity” of water across the Mediterranean, which is normally higher for Northern than for Southern countries. In table 8, the values of **water productivity (WP)** for each crop is reported, as chosen close or within the range of suggested values of the so-called **water utilization efficiency for harvestable yield** as reported by FAO Water (*online*).

Tab. 8 – Selected values of water productivity (WP) for the estimation of maximum yield for wheat, maize, tomato, potato and olive.

Crop	Crop water productivity (CWP) (kg m ⁻³) (*)		Water utilization efficiency for harvestable yield (kg m ⁻³) (**)	Water productivity (kg m ⁻³) (***)	
	Southern Mediterranean countries	Northern Mediterranean countries		Southern Mediterranean countries	Northern Mediterranean countries
Wheat	0.6 (±0.1)	0.7 (±0.3)	0.8 – 1.6	1.0	1.1 – 1.6
Tomato	6.2 (±0.9)	9.0 (±5.2)	10.0 – 12.0	10.0	12.0 – 13.0
Potato	4.2 (±0.3)	5.5 (±1.0)	4.0 – 7.0	5.0 – 6.0	6.5
Maize	1.0 (±0.1)	1.3 (±0.3)	0.8 – 1.6	1.3	1.5
Olive	0.5 (±0.1)	0.6 (±0.2)	1.5 – 2.0	1.5	1.5 - 2

(*) As estimated in WasserMed Deliverable n. 4.3.1

(**) As reported in FAO Water (online).

(***) Values selected for the present research

2.3. Adaptation measures

Farm adaptation strategies to climate change (such as shifting of sowing/planting date, changing cultivar type, managing different irrigation strategies, etc.) will have different results with respect to different agricultural systems, location and scenarios of climate change considered (Rosenzweig and Tubiello, 2007; Reidsma et al., 2010). The impact of some selected adaptation measures and management practices has been then evaluated.

2.3.1. Sowing/planting date (field crops and vegetables)

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 9. In the case of olive, the starting of the cropping cycle has been taken as “fixed” (1st 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.

Tab. 9 – 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	01/03

2.3.2. Variety selection (late varieties)

As previously mentioned, a linear 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 relative increase in 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 relative 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 (as presented in paragraph 2.4) 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 (Wheeler et al. 2000; Tubiello et al., 2000).

Tab. 10 – Modified values of *GDD* sum required for the simulation of wheat, maize, tomato and potato development (late variety type).

Crop	Modified GDD sum (°C)			
	(initial)	(development)	(mid-season)	(late)
Wheat	275	1375	2090	2750
Tomato	110	550	990	1320
Potato	165	605	1320	1760
Maize	110	715	1430	1760

With this choice, the total cropping cycle length of the adapted varieties under “future” climate has been found to be quite always comparable in length to that of the ones used under “present” climate conditions. The relative effect of this strategy on both crop water requirements and yield has been assessed.

2.3.3. Irrigation scheduling strategies

The effect of different irrigation strategies has been also considered. More specifically, the application of a **deficit irrigation (DI)** strategy has been evaluated in order to reduce crop water consumption to counterbalance the expected increase of daily ET_c 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 ET_c and no reduction in yield is expected. On the contrary, with a “deficit irrigation” strategy crop ET_c is fully satisfied only during the selected drought-sensitive stages, while otherwise a certain level of water stress is allowed. As a consequence, yield reduction is expected, and its level will depend on the crop K_y values for the given stage and the severity of ET_c 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 the selected crops. The following different combinations of model parameters for irrigation scheduling (MAD and Kia) have been selected (as a function of the depletion fraction p), together with the selection of some critical crop specific Ky , as summarized in the tables 11-12 and figure 3.

Tab. 11 – 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	

Tab. 12 – Crop growth stages with the higher sensitivity (higher Ky) to water stress.

Crop	Initial	Development	Mid-season	Late
Maize	0.4	0.4	1.3 Flowering to grain filling	0.5
Wheat	0.2	0.6 Booting to flowering	0.5	0.3
Potato	0.45	0.8 From tuber initiation to yield formation	0.8	0.3
Tomato	0.4	0.4	1.1 Yield formation	0.6
Olive	0.2	0.5*	0.8* Yield formation	0.5*

*Estimated by the authors

2.4. Simulated scenarios for case-study area.

As a summary, the following combination of crop type, climate scenarios and adaptation strategies have been tested for each case-study area.

Tab. 13 – 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	Shifting sowing date	Late 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

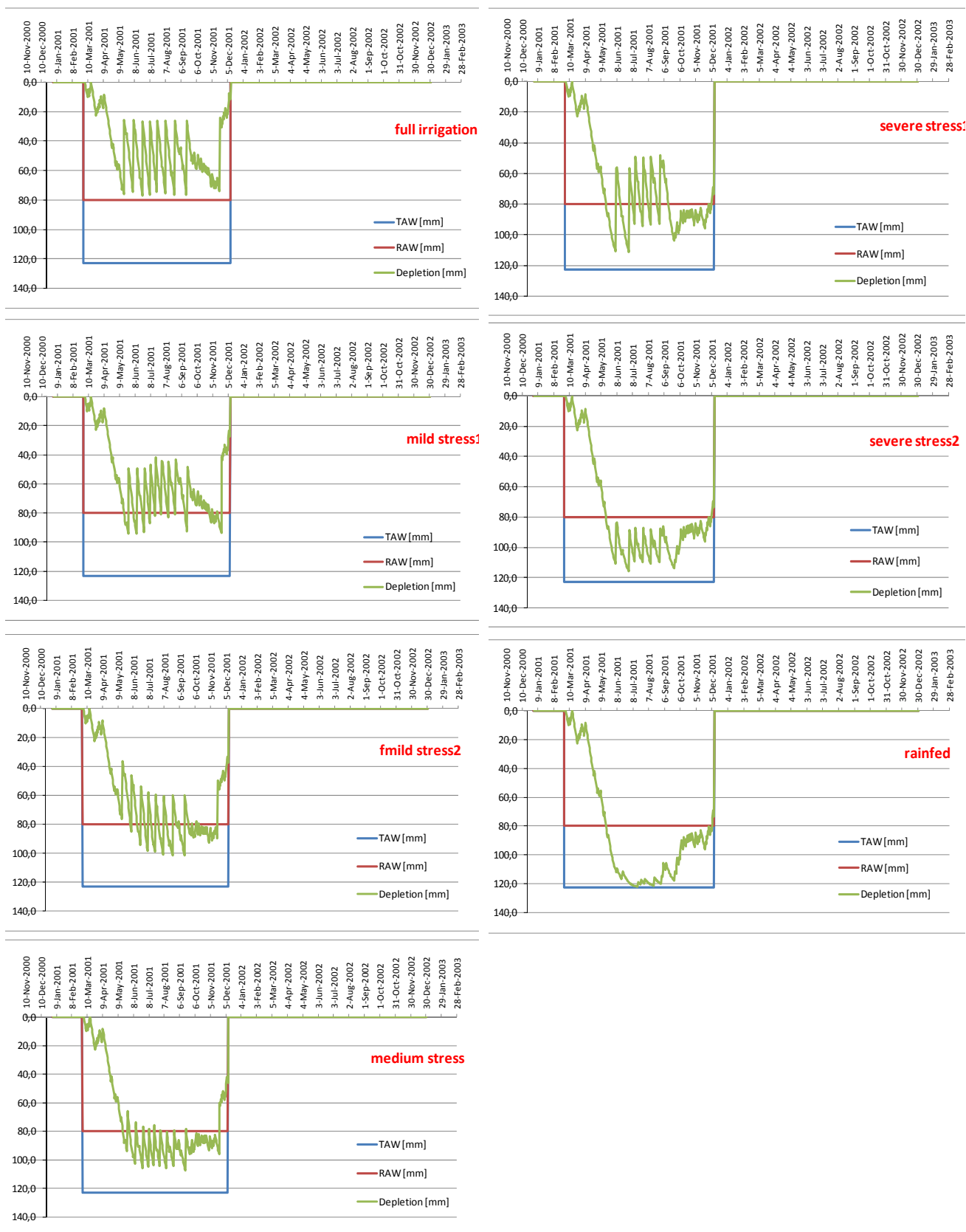


Fig. 3 – Example of simulation curves of soil water depletion under different irrigation strategies for olive crop.

3. Case study: Jordan river basin (Jordan)

3.1. Climate projections and reference evapotranspiration

With respect to climate projections, as summarized in the following tables and graphs, the following observation are predicted:

- a relative stability of the annual rainfall pattern (also considering the relatively low values), with light variations at monthly scale;
- a relevant increase (+121 mm) of annual reference evapotranspiration, especially during spring-summer months (with values up to 13 mm/month), with a “peak” of daily evapotranspiration in July (9.5 mm/day);

Tab. 13 – Monthly and annual average values and relative variations of predicted rainfall and evapotranspiration under present and future climate conditions in Jordan river basin (Jordan).

Month	Rain			ETo		
	2000	2050	var. (mm)	2000	2050	var. (mm)
1	23.5	14.8	-8.76	67.5	75.0	7.43
2	14.4	16.8	2.39	84.1	91.3	7.26
3	13.0	16.5	3.54	134.5	143.8	9.35
4	14.4	12.4	-2.02	171.7	184.3	12.60
5	5.7	5.0	-0.77	233.6	246.7	13.07
6	5.3	5.3	0.06	268.8	281.7	12.87
7	5.7	5.3	-0.40	280.5	293.6	13.13
8	7.5	10.7	3.22	267.3	280.3	13.06
9	11.7	7.3	-4.41	206.8	219.7	12.90
10	16.2	20.4	4.20	146.1	153.8	7.67
11	21.0	22.5	1.50	89.2	95.9	6.70
12	22.5	23.0	0.53	67.5	72.5	5.03
Total	160.9	160.0	-0.9	2017.6	2138.7	121.1

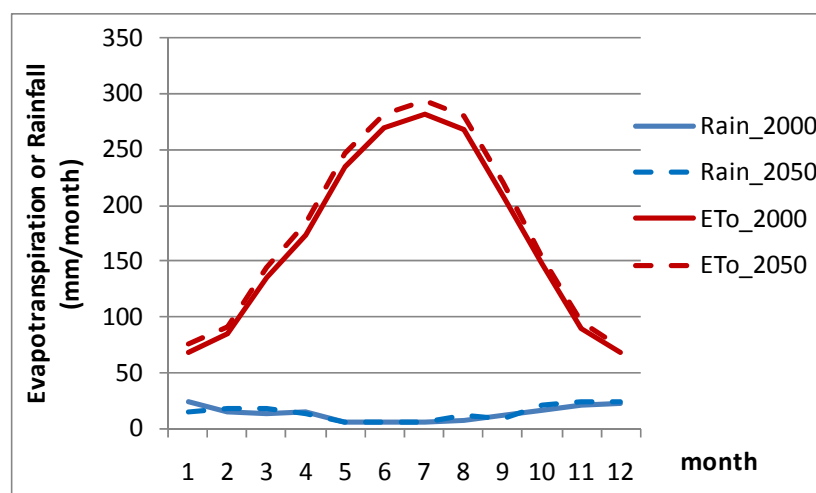


Fig. 4 – Monthly trends of predicted rainfall and evapotranspiration under present and future climate conditions in Jordan river basin (Jordan).

- an important increase in annual average maximum, minimum and average air temperatures, up to +1.9°C;
- a relatively distributed increase in monthly average maximum, minimum and average air temperature, with values ranging from +1.6 to 2°C/month;
- an increase in the “peak” air temperature during the hottest month of July, with average maximum value projected to reach 38.9°C.

Tab. 14 – Monthly and annual average values and relative variations of predicted maximum, minimum and average air temperature under present and future climate conditions in Jordan river basin (Jordan).

Month	Tmax			Tmin			Tmean		
	2000	2050	var. (°C)	2000	2050	var. (°C)	2000	2050	var. (°C)
1	15.0	17.1	2.1	4.4	6.2	1.7	9.7	11.7	1.9
2	17.6	19.3	1.7	5.6	7.1	1.6	11.6	13.2	1.6
3	21.8	23.5	1.8	8.6	10.4	1.7	15.2	17.0	1.7
4	26.2	27.9	1.8	12.4	14.0	1.6	19.3	21.0	1.7
5	31.2	33.0	1.9	16.6	18.3	1.7	23.9	25.7	1.8
6	34.9	36.9	2.0	19.8	21.7	1.9	27.4	29.3	1.9
7	37.0	38.9	1.9	22.2	24.0	1.8	29.6	31.5	1.9
8	36.7	38.6	1.9	22.5	24.4	1.9	29.6	31.5	1.9
9	33.4	35.5	2.0	20.2	22.2	2.0	26.8	28.8	2.0
10	28.4	30.1	1.7	16.3	18.2	1.9	22.4	24.2	1.8
11	21.8	23.5	1.7	10.8	12.5	1.7	16.3	18.0	1.7
12	16.1	18.2	2.1	5.9	7.8	1.9	11.0	13.0	2.0
Average	26.7	28.6	1.9	13.8	15.6	1.8	20.2	22.1	1.8

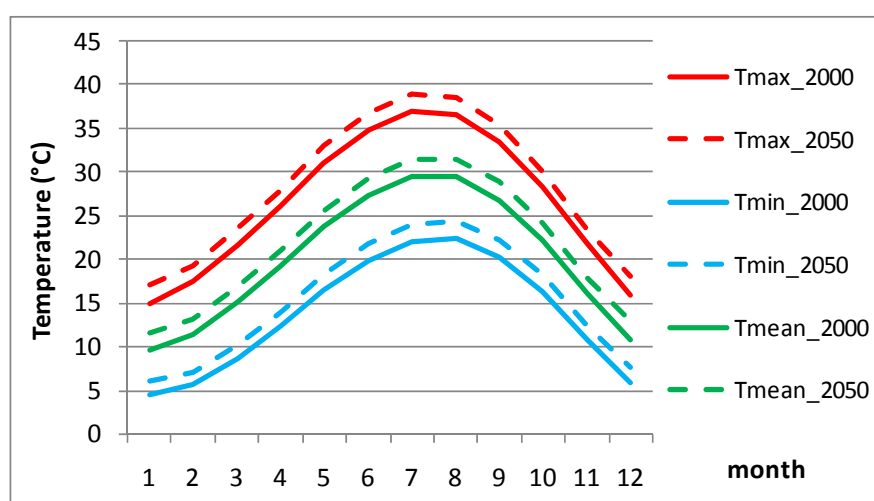


Fig. 5 – Monthly trends of predicted maximum, minimum and mean air temperatures under present and future climate conditions in Jordan river basin (Jordan).

3.2. Wheat

3.2.1. Cycle length and crop coefficient curves

The effect of temperature increase (and relative GDD accumulation) on current and projected crop cycle length and corresponding crop coefficient curves is represented in Figures 6 and 7. Following observations have to be highlighted:

- with respect to the four crop coefficient stages, a relative reduction of growing period is predicted as a proportion to the corresponding increase in the cumulative GDD (lower during winter, higher during spring-summer months), both in the case of early (November) and late (February) sowing dates (fig. 6);
- if varietal adaptation is not considered, an important reduction of the total growing cycle is predicted for all planting dates, because of the faster accumulation of the required GGD sum under “future” climate conditions (2050) (fig. 6-7);
- on the contrary, if a late maturing variety will be used, the total crop cycle length (2050 late_var) is projected to remain relatively the same as for the current variety under “present” climate conditions (2000) (fig. 7);

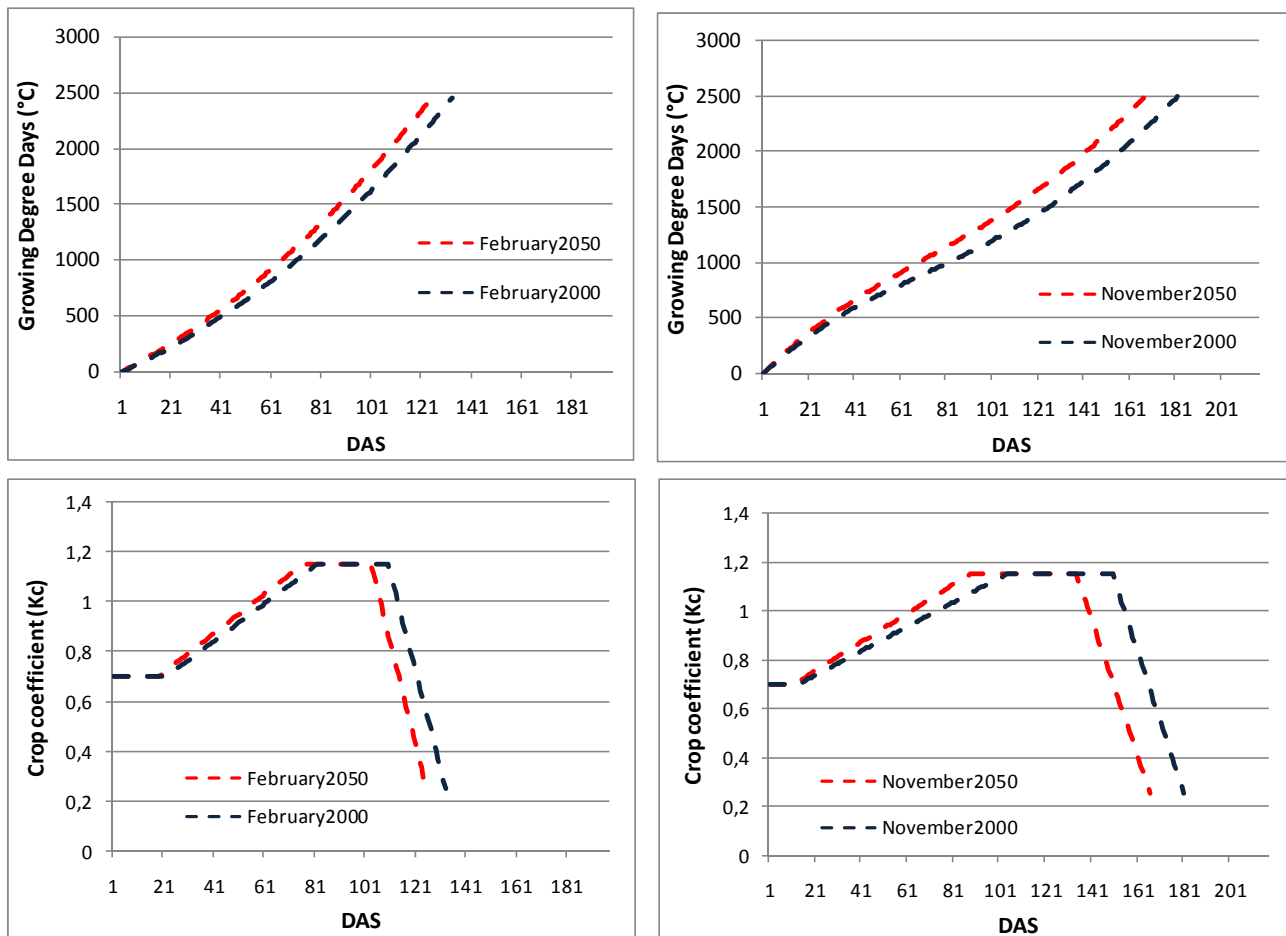


Fig. 6 – Predicted cumulative GDD and corresponding Kc curves for wheat in Jordan river basin (Jordan) as affected by different planting dates and climate scenarios.

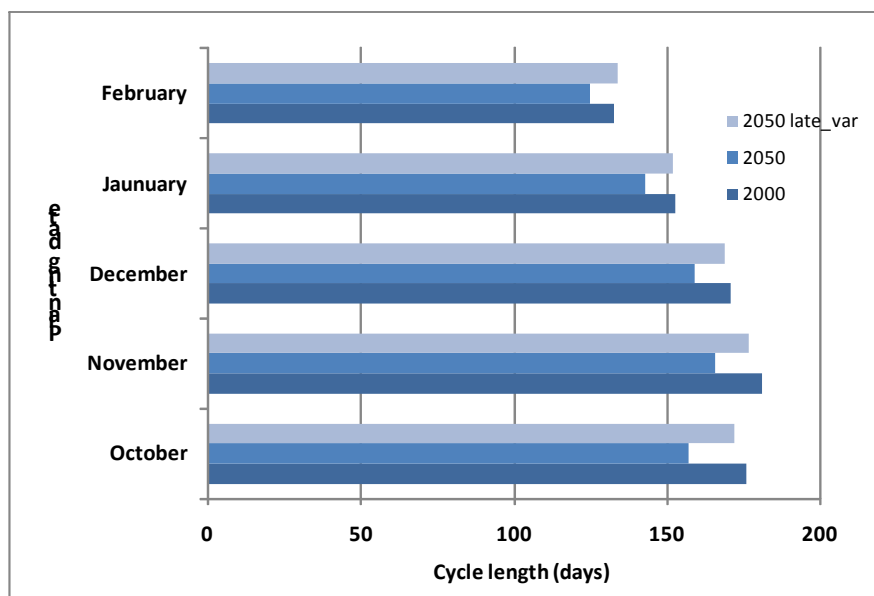


Fig. 7 – Length of total growing cycle of wheat in Jordan river basin (Jordan) as affected by planting date, variety selection and climate variations.

3.2.2. Crop evapotranspiration and irrigation requirements.

The impact of climate change on maximum and effective crop evapotranspiration as well as on net irrigation requirements, also considering the relative effect of selected adaptation strategies (planting dates, variety selection and deficit irrigation strategies), is summarized in the following tables and graphs. In brief, the following observations are reported:

- maximum seasonal crop evapotranspiration is projected to reduce for the current variety under “future” (2050) scenario as a consequence of the expected shortening of the crop growing cycle, on average of about -6.5% with respect to current conditions (2000) (fig. 9 and tab.15);
- on the contrary, if a late maturing variety (2050 late_var) is selected, maximum evapotranspiration is projected to remain stable or to increase (+5%) for all the planting dates (fig. 9 and tab.15);
- the relative effect of the projected variation of rainfall patterns seems to be slightly relevant for the crop water balance, due to their very low values (tab.16);
- maximum seasonal crop evapotranspiration is observed always to increase (in absolute terms) for late (February) planting date with respect to earlier (October) ones, because of the shifting of most of the cycle towards the spring-summer season (fig. 9 and tab.15);
- effective seasonal crop evapotranspiration and net irrigation requirements are both highly dependent on the irrigation strategy, progressively reducing going from full irrigation to rainfed conditions (fig. 9 and tab.17-18);
- as for ET_{c_max} , also the ET_{c_eff} and NIR are projected to decrease in 2050 if the current variety is used, or to increase if a late maturing variety is selected, especially under full irrigated conditions (fig.9 and tab.17-18);

Tab.15 – Effect of planting date and variety selection on the maximum crop evapotranspiration of wheat in Jordan river basin (Jordan) under “present” and “future” climate conditions.

Planting date	ETc_max 2000	ETc_max 2050		ETc_max 2050 late_var	
	[mm/season]	[mm/season]	(variation vs 2000)	[mm/season]	(variation vs 2000)
october	476.7	436.2	-8.5%	494.5	3.7%
november	547.4	497.1	-9.2%	562.9	2.8%
december	609.8	567.3	-7.0%	636.6	4.4%
january	624.9	590.8	-5.5%	660.2	5.6%
february	667.6	644.6	-3.4%	719.9	7.8%
average	585.3	547.2	-6.5%	614.8	5.0%

Tab.16 – Effect of planting date and variety selection on the effective rainfall pattern during crop cycle of wheat in Jordan river basin (Jordan) under “present” and “future” climate conditions.

Planting date	Rain_eff 2000	Rain_eff 2050		Rain_eff 2050 late_var	
	[mm/season]	[mm/season]	(variation vs 2000)	[mm/season]	(variation vs 2000)
october	83.0	78.6	-5.3%	83.9	1.1%
november	87.0	80.8	-7.1%	82.8	-4.9%
december	68.4	66.8	-2.4%	66.8	-2.4%
january	41.0	42.5	3.7%	42.5	3.7%
february	32.3	36.6	13.3%	36.6	13.3%
average	62.3	61.0	-2.1%	62.5	0.3%

Tab.17– Effect of irrigation strategies and variety selection on the effective crop evapotranspiration of wheat in Jordan river basin (Jordan) under “present” and “future” climate.

Irrigation strategy	ETc_eff 2000	ETc_eff 2050		ETc_eff 2050 late_var	
	[mm/season]	[mm/season]	(variation vs 2000)	[mm/season]	(variation vs 2000)
full	585.2	547.1	-6.5%	614.7	5.1%
mild1	559.9	512.9	-8.4%	588.8	5.2%
mild2	522.0	490.2	-6.1%	544.1	4.2%
medium	483.4	414.8	-14.2%	503.3	4.1%
severe1	432.2	398.9	-7.7%	450.1	4.1%
severe2	332.8	295.5	-11.2%	341.6	2.7%
rainfed	179.1	173.6	-3.1%	176.5	-1.5%

Tab. 18– Effect of irrigation strategies and variety selection on the net irrigation requirements of wheat in Jordan river basin (Jordan) under “present” and “future” climate conditions.

Irrigation strategy	NIR 2000	NIR 2050		NIR 2050 late_var	
	[mm/season]	[mm/season]	(variation vs 2000)	[mm/season]	(variation vs 2000)
full	486.3	454.7	-6.5%	516.3	6.2%
mild1	435.3	407.7	-6.3%	470.1	8.0%
mild2	389.1	363.7	-6.5%	413.1	6.2%
medium	339.9	288.4	-15.1%	375.6	10.5%
severe1	282.9	265.0	-6.3%	305.6	8.0%
severe2	169.9	144.2	-15.1%	187.8	10.5%
rainfed	0.0	0.0	0.0%	0.0	0.0%

- by plotting together the values of seasonal ETc_{eff} and NIR (obtained under different irrigation strategies and variety) for different climate scenarios, there is a clear prediction of their reduction (respectively of about -8.6% and -7.7%, on average) while, by considering a late maturing variety, an increase of both (respectively of about +4.4% and +8%, on average) (fig. 8);
- the cumulative curves of ETc_{max} in 2050 (versus 2000) show always (also under different planting dates) their shifting towards higher values, thus representing the relative increase in daily crop water requirements, although with a decrease in the cumulative final value (depending on the anticipated ending of the cycle) (fig. 10).

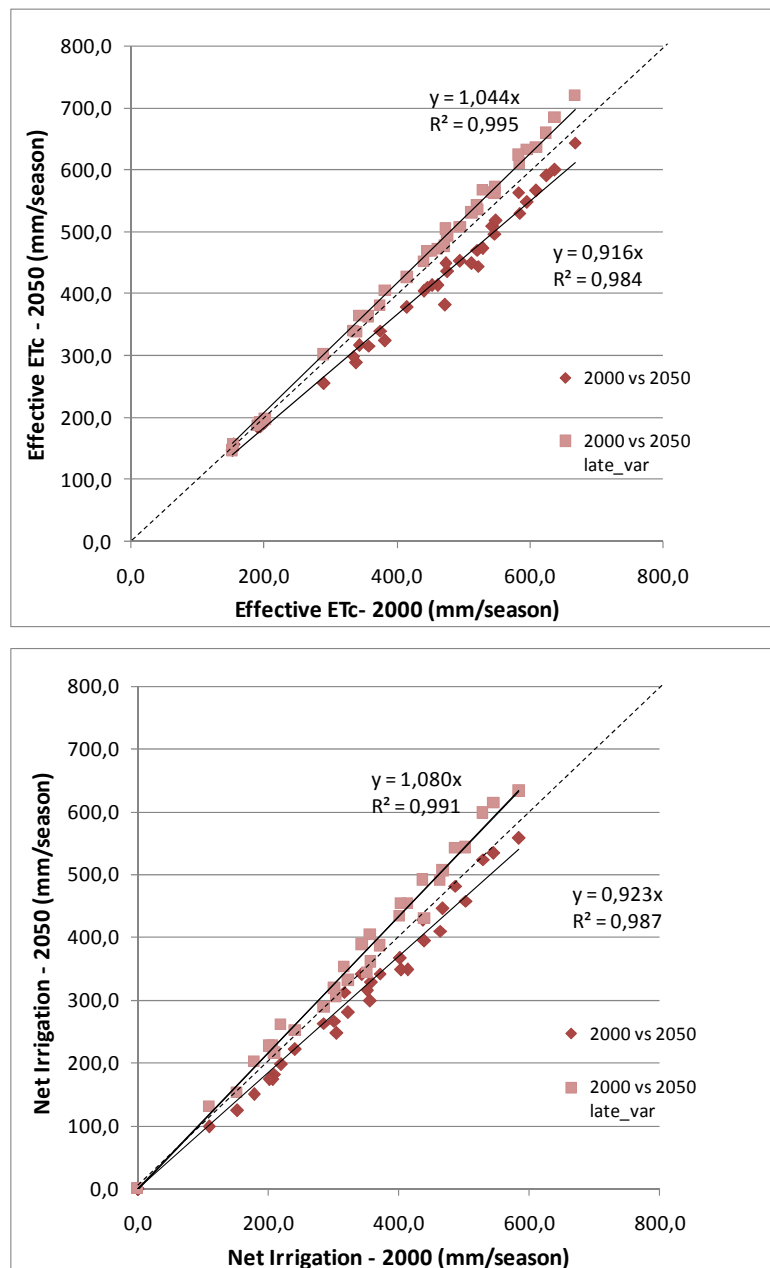


Fig. 8 – Scatter-plot of seasonal crop evapotranspiration and net irrigation requirements of as affected by different variety selection for wheat in Jordan river basin (Jordan) under “present” and “future” climate conditions.

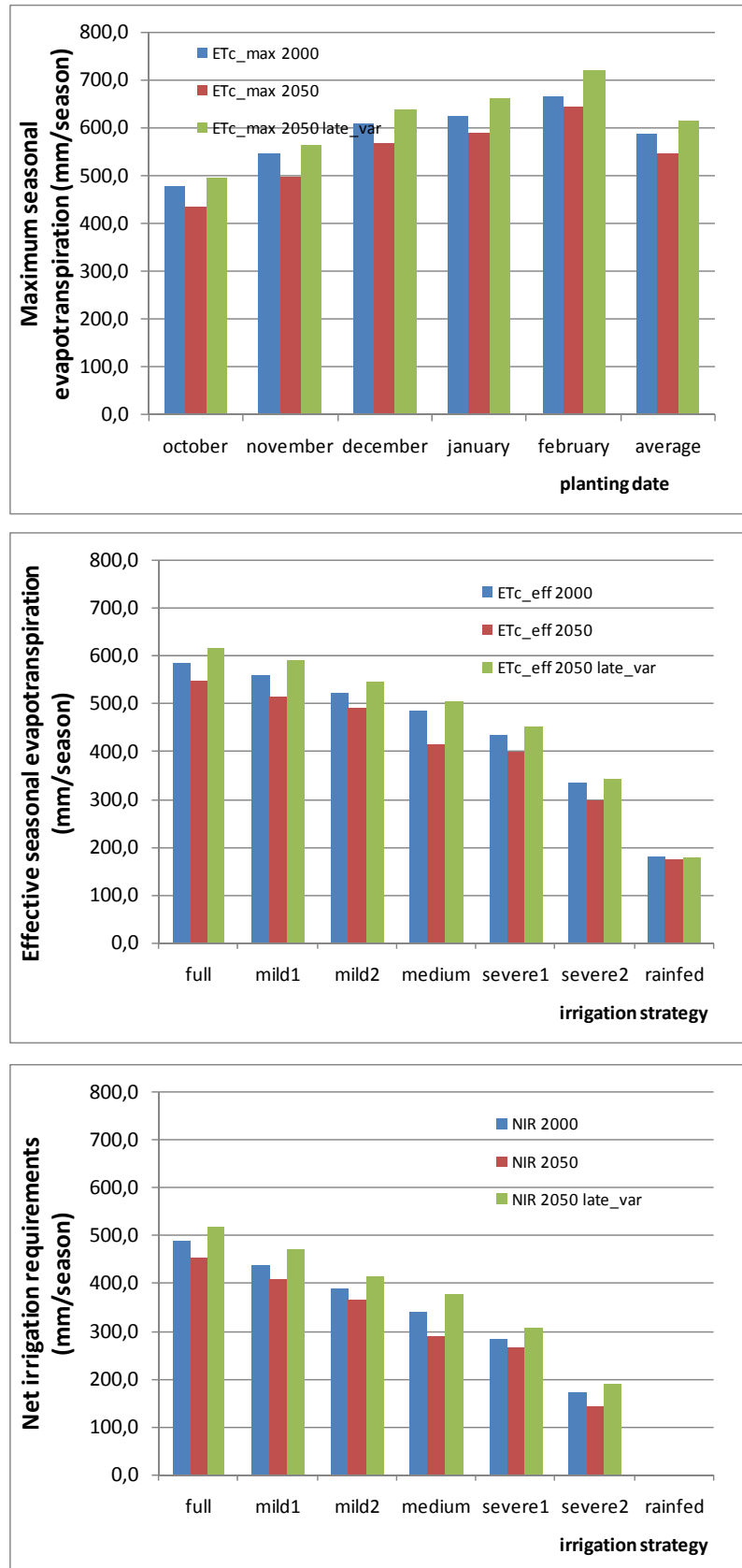


Fig. 9 – Effect of planting date, irrigation strategies and variety selection on maximum and effective crop evapotranspiration and net irrigation requirements of wheat in Jordan river basin (Jordan) under “present” and “future” climate conditions.

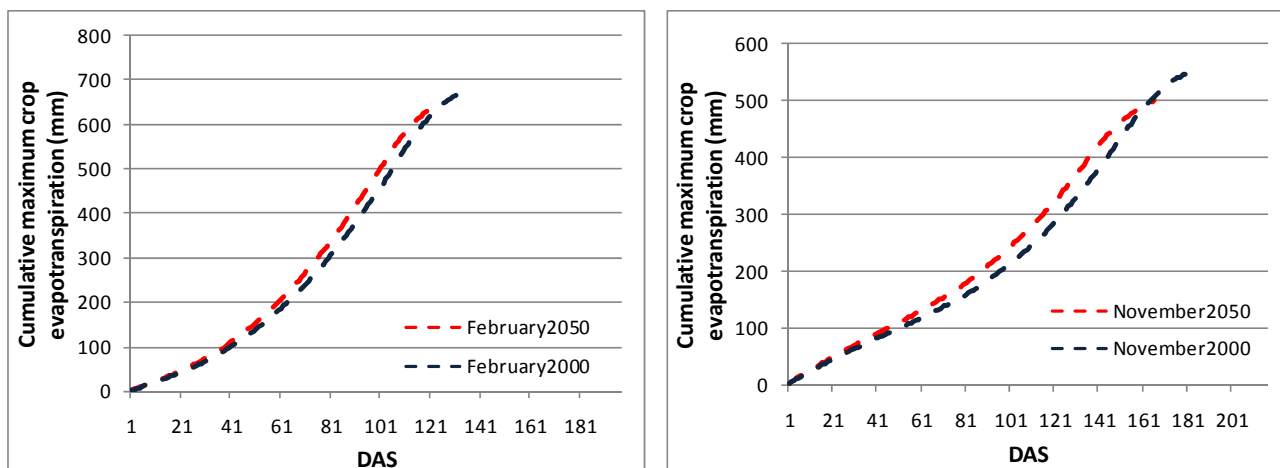


Fig. 10 – Cumulative curves of maximum crop evapotranspiration as affected by different planting date for wheat in Jordan river basin (Jordan) under “present” and “future” climate conditions.

3.2.3. Crop evapotranspiration under extreme weather conditions

If a simulated future “extreme weather” climate condition (2050+1) is considered (created by adding +1°C to daily temperature of 2050 climate scenario), the following observations on crop cycle length are reported (fig. 11):

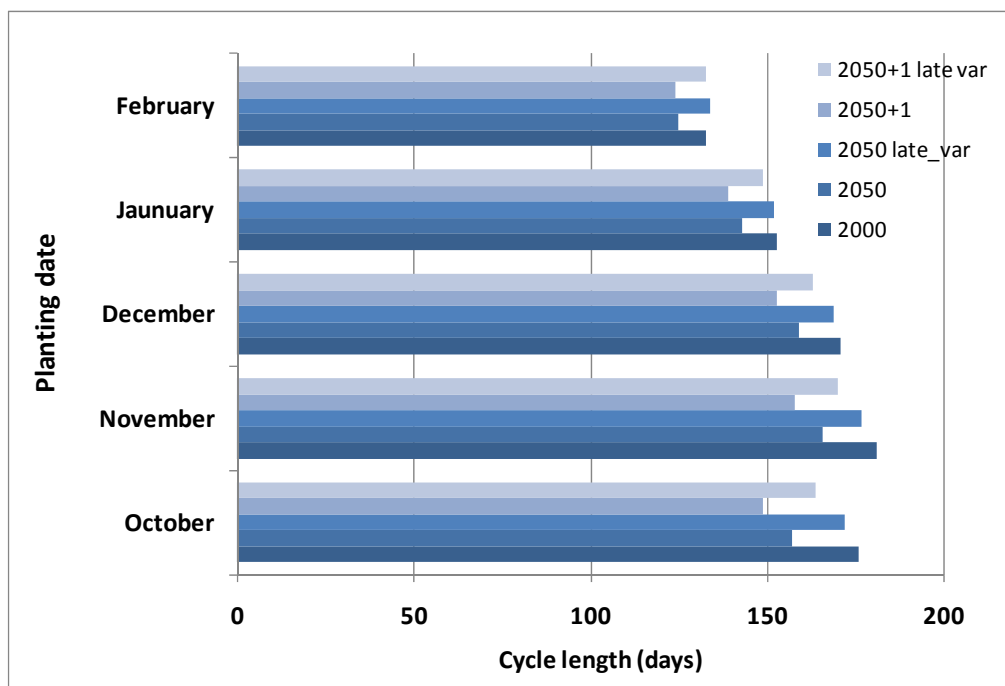


Fig. 11 – Length of total growing cycle of wheat in Jordan river basin (Jordan) as affected by planting date and variety selection under “present (2000)”, “future (2050)” and “future extreme weather (2050+1)” climate conditions.

- with current variety, a further important reduction of the total growing cycle is predicted for quite all planting dates with respect to 2000 and 2050 scenario, because of the further faster accumulation of the required GDD sum;
- if a late maturing variety is considered, the total crop cycle length (2050+1 late_var) is partly recovered with respect to present (2000) scenario only in the case of late planting dates (January, February), while it is significantly shortened in all other cases with respect to 2050 late_var and 2000 scenarios.

The impact of future “extreme weather” conditions (2050+1) on maximum and effective crop evapotranspiration as well as on net irrigation requirements, also considering the relative effect of selected adaptation strategies (planting dates, variety selection and deficit irrigation strategies), is summarized in the following tables and graphs. In brief, the following observations are reported:

- *ETc_max* is projected to reduce for the current variety under future “extreme weather” (2050+1) scenario as a consequence of the expected further shortening of the crop growing cycle, on average of about -9.2% with respect to present conditions (2000); on the contrary, if a late maturing variety (2050+1 late_var) is selected, *ETc_max* is projected to remain stable or to increase (+2.8% on average) (tab.19);
- *ETc_max* is observed always to increase (in absolute terms) for late (February) planting date with respect to earlier (October) ones, because of the shifting of most of the cycle towards the hotter spring-summer season (fig. 12 and tab. 19);
- the relative effect of the projected variation of rainfall patterns (close to -40%) seems to be slightly relevant for the crop water balance, due to their very low absolute values (tab.20);
- *ETc_eff* and *NIR* are both projected to decrease under 2050+1 scenario if the current variety is used, or again to increase if a late maturing variety is selected (tab. 21-22), always with respect to 2000 baseline scenario;
- *ETc_eff* and *NIR* are both highly dependent on the irrigation strategy, progressively reducing going from full irrigation to rainfed conditions, under all climate scenarios (fig. 12);
- by plotting together the values of seasonal *ETc_eff* and *NIR* for 2000 versus 2050+1 climate scenarios, there is a clear prediction of their reduction (respectively of about -9.6% and -4.4%, on average), or of their increase if a late maturing variety is considered (respectively of about +1.4% and +11.1%, on average) (fig. 13 and tab. 21-22);

Tab. 19 – Effect of planting date and variety selection on the maximum crop evapotranspiration of wheat in Jordan river basin (Jordan) under “present”, “future” and “future extreme weather” climate conditions.

Planting date	ETc_max 2000	ETc_max 2050		ETc_max 2050 late_var		ETc_max 2050+1		ETc_max 2050+1 late_var	
	(mm)	(mm)	var.% (2000)	(mm)	var.% (2000)	(mm)	var.% (2000)	(mm)	var.% (2000)
october	476.7	436.2	-8.5%	494.5	3.7%	422.7	-11.3%	476.2	-0.1%
november	547.4	497.1	-9.2%	562.9	2.8%	469.1	-14.3%	537.9	-1.7%
december	609.8	567.3	-7.0%	636.6	4.4%	539.9	-11.5%	610.1	0.0%
january	624.9	590.8	-5.5%	660.2	5.6%	574.5	-8.1%	652.0	4.3%
february	667.6	644.6	-3.4%	719.9	7.8%	650.7	-2.5%	730.8	9.5%
average	585.3	547.2	-6.5%	614.8	5.0%	531.4	-9.2%	601.4	2.8%

Tab. 20 – Effect of planting date and variety selection on the effective rainfall pattern during crop cycle of wheat in Jordan river basin (Jordan) under “present”, “future” and “future extreme weather” climate conditions.

Planting date	Rain_eff 2000	Rain_eff 2050		Rain_eff 2050 late_var		Rain_eff 2050+1		Rain_eff 2050+1 late_var	
	(mm)	[mm/season]	var.% (2000)	(mm)	var.% (2000)	(mm)	var.% (2000)	(mm)	var.% (2000)
october	83.0	78.6	-5.3%	83.9	1.1%	54.1	-34.8%	56.9	-31.5%
november	87.0	80.8	-7.1%	82.8	-4.9%	52.4	-39.8%	52.4	-39.8%
december	68.4	66.8	-2.4%	66.8	-2.4%	39.8	-41.8%	39.8	-41.8%
january	41.0	42.5	3.7%	42.5	3.7%	22.8	-44.3%	22.8	-44.3%
february	32.3	36.6	13.3%	36.6	13.3%	18.7	-42.2%	18.7	-42.2%
average	62.3	61.0	-2.1%	62.5	0.3%	37.6	-39.8%	38.1	-38.9%

Tab. 21 – Effect of irrigation strategies and variety selection on the effective crop evapotranspiration of wheat in Jordan river basin (Jordan) under “present”, “future” and “future extreme weather” climate conditions.

Irrigation strategy	ETc_eff 2000	ETc_eff 2050		ETc_eff 2050 late_var		ETc_eff 2050+1		ETc_eff 2050+1 late_var	
	(mm)	(mm)	var.% (2000)	(mm)	var.% (2000)	(mm)	var.% (2000)	(mm)	var.% (2000)
full	585.2	547.1	-6.5%	614.7	5.1%	531.4	-9.2%	601.3	2.8%
mild1	559.9	512.9	-8.4%	588.8	5.2%	506.2	-9.6%	576.0	2.9%
mild2	522.0	490.2	-6.1%	544.1	4.2%	473.9	-9.2%	529.2	1.4%
medium	483.4	414.8	-14.2%	503.3	4.1%	435.9	-9.8%	489.8	1.3%
severe1	432.2	398.9	-7.7%	450.1	4.1%	387.7	-10.3%	433.1	0.2%
severe2	332.8	295.5	-11.2%	341.6	2.7%	295.2	-11.3%	323.2	-2.9%
rainfed	179.1	173.6	-3.1%	176.5	-1.5%	151.2	-15.6%	152.9	-14.6%

Tab.22 – Effect of irrigation strategies and variety selection on the net irrigation requirements of wheat in Jordan river basin (Jordan) under “present”, “future” and “future extreme weather” climate conditions.

Irrigation strategy	NIR 2000	NIR 2050		NIR 2050 late_var		NIR 2050+1		NIR 2050+1 late_var	
	(mm)	(mm)	var.% (2000)	(mm)	var.% (2000)	(mm)	var.% (2000)	(mm)	var.% (2000)
full	486.3	454.7	-6.5%	516.3	6.2%	448.8	-7.7%	532.5	9.5%
mild1	435.3	407.7	-6.3%	470.1	8.0%	419.0	-3.7%	484.3	11.3%
mild2	389.1	363.7	-6.5%	413.1	6.2%	359.0	-7.7%	426.0	9.5%
medium	339.9	288.4	-15.1%	375.6	10.5%	340.6	0.2%	389.2	14.5%
severe1	282.9	265.0	-6.3%	305.6	8.0%	272.3	-3.7%	314.8	11.3%
severe2	169.9	144.2	-15.1%	187.8	10.5%	170.3	0.2%	194.6	14.5%
rainfed	0.0	0.0		0.0		0.0		0.0	

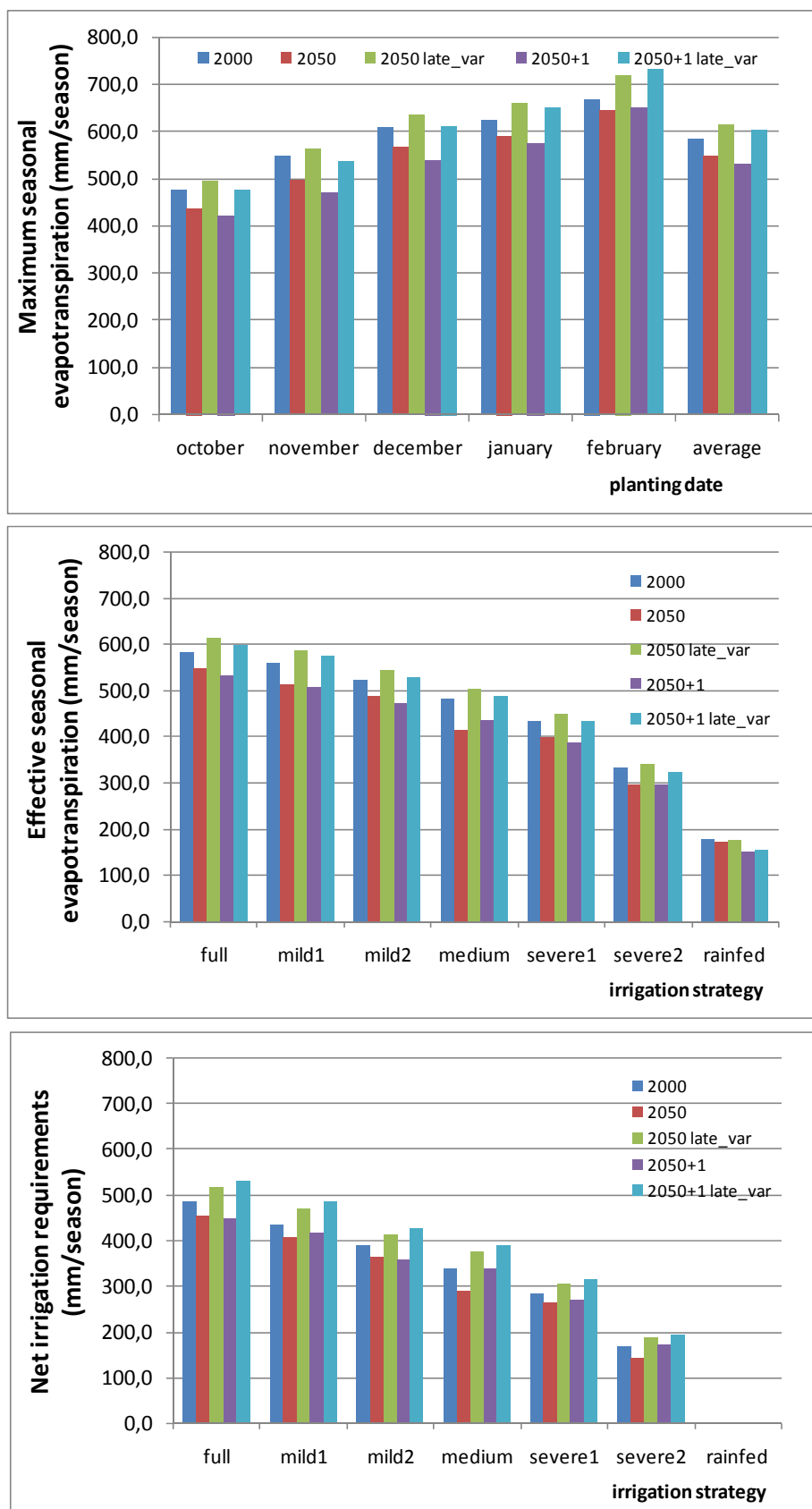


Fig. 12 – Effect of planting date, irrigation strategies and variety selection on maximum and effective crop evapotranspiration and net irrigation requirements of wheat in Jordan river basin (Jordan) under “present” and “future” and “extreme weather (2050+1)” climate conditions.

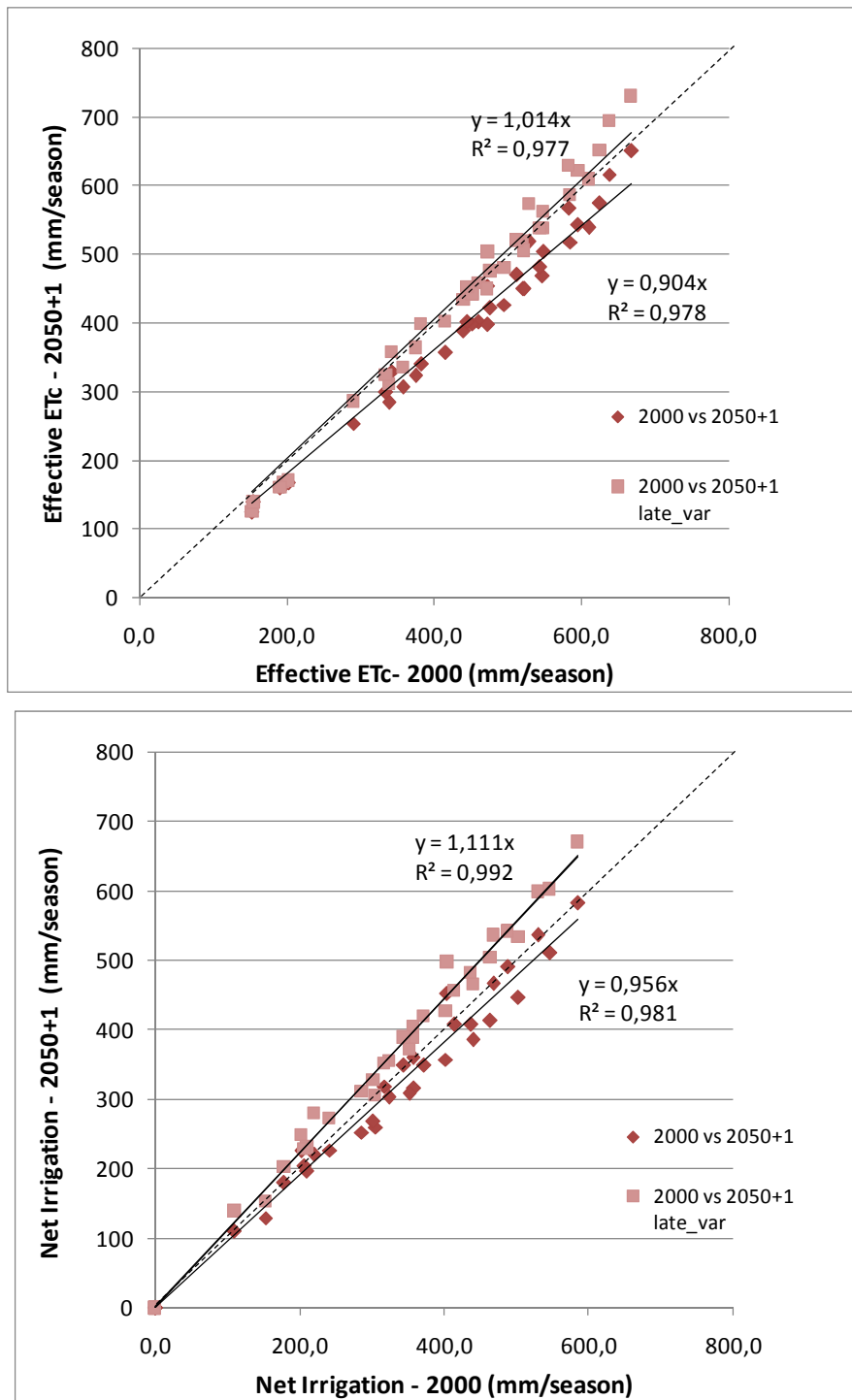


Fig. 13 – Scatter-plot of seasonal crop evapotranspiration and net irrigation requirements of as affected by different variety selection for wheat in Jordan river basin (Jordan) under “present (2000)” and “future extreme weather (2050+1)” climate conditions.

3.2.4. Yield response to water

The impact of “future” climate projections (2050) and “extreme weather” (2050+1) on potential yield, also considering the relative effect of selected adaptation strategies (planting dates, variety selection and deficit irrigation strategies), is summarized in the following tables and graphs. In brief, the following observations are reported:

- maximum yield is expected to reduce under “future” scenario (2050) with respect to current conditions (2000), on average from 5.9 to 5.5 t ha⁻¹ (about -6.5%), depending on irrigation strategies (tab. 23 and fig.14) and planting dates (tab. 24 and fig. 14) as a consequence of the expected shortening of the crop growing cycle;
- on the contrary, if the expected fertilizing effect due to increase in atmospheric CO₂ concentration will occur, yield is projected to increase in quite all conditions (2050 wp_adj), up to an average of 6.6 t ha⁻¹ (+12.2%), and thus to overcome the effect of the shortening of the crop cycle (fig. 14 and tab. 23-24);
- on the other side, if a late maturing variety (2050 late_var) is selected, yield is projected to increase up to an average of 6.1 t ha⁻¹ (+5%), especially under fully irrigation (fig. 14 and tab. 23-24);
- if “extreme weather” conditions (2050+1) are considered, the average expected yield reduction (down to 5.3 t ha⁻¹, -9.2%) is greater than in 2050 scenario, but also in this case it could be completely recovered because of the CO₂ fertilizing effect or the late-variety selection, respectively to 6.4 t ha⁻¹ (+5%) and 6 t ha⁻¹ (+2.8%);
- with respect to irrigation strategies, there is a clear reduction in potential yield under increasing water stress conditions (fig. 14), but still under “severe” water stress (thus only supported by supplemental irrigations) values up to 3-4 t ha⁻¹ are expected, while under rainfed conditions, an average yield of 1.5 t ha⁻¹ is still predicted in all climate conditions;
- yield is observed always to increase (in absolute terms) for late (February) planting date with respect to earlier (October) ones (fig. 14), but a corresponding increase in crop water requirements is clearly projected (as it has been highlighted in the previous paragraph).

Tab. 23– Effect of irrigation strategies, variety selection and atmospheric CO₂ increase on the potential yield of wheat in Jordan river basin (Jordan) under “present”, “future” and “extreme weather” climate conditions.

Irrigation strategy	Yield 2000 (*)	Yield 2050 (*)		Yield 2050 wp_adj (**)		Yield 2050 late_var (*)		Yield 2050+1 (*)		Yield 2050+1 wp_adj (**)		Yield 2050+1 late_var (*)	
	(t/ha)	(t/ha)	var.% (2000)	(t/ha)	var.% (2000)	(t/ha)	var.% (2000)	(t/ha)	var.% (2000)	(t/ha)	var.% (2000)	(t/ha)	var.% (2000)
full	5.9	5.5	-6.5%	6.6	12.2%	6.1	5.0%	5.3	-9.2%	6.4	8.9%	6.0	2.8%
mild1	5.5	5.0	-9.4%	6.0	8.7%	5.8	5.0%	5.0	-9.8%	6.0	8.3%	5.7	2.8%
mild2	4.9	4.6	-5.7%	5.6	13.2%	5.1	4.1%	4.5	-9.0%	5.4	9.2%	5.0	1.2%
medium	4.5	3.7	-17.5%	4.5	-1.0%	4.7	4.1%	4.1	-9.8%	4.9	8.3%	4.6	1.1%
severe1	3.8	3.5	-8.4%	4.2	9.9%	4.0	4.0%	3.4	-10.4%	4.1	7.5%	3.8	-0.1%
severe2	2.8	2.5	-12.9%	2.9	4.6%	2.9	3.2%	2.5	-10.7%	3.0	7.2%	2.8	-2.2%
rainfed	1.5	1.5	-3.2%	1.8	16.1%	1.5	1.6%	1.3	-13.2%	1.6	4.2%	1.4	-8.0%
(*) assuming wp (2000) = 1 (kg/m3)													
(**) assuming wp (2050)= wp(2000)*1.2= 1.2 (kg/m3)													

Tab. 24 – Effect of planting date, variety selection and atmospheric CO₂ increase on the potential yield of wheat in Jordan river basin (Jordan) under “present”, “future” and “extreme weather” climate conditions.

Irrigation strategy	Yield 2000 (*)	Yield 2050 (*)		Yield 2050 wp_adj (**)		Yield 2050 late_var (*)		Yield 2050+1 (*)		Yield 2050+1 wp_adj (**)		Yield 2050+1 late_var (*)	
	(t/ha)	(t/ha)	var.% (2000)	(t/ha)	var.% (2000)	(t/ha)	var.% (2000)	(t/ha)	var.% (2000)	(t/ha)	var.% (2000)	(t/ha)	var.% (2000)
october	4.8	4.4	-8.5%	5.2	9.8%	4.9	3.7%	4.2	-11.3%	5.1	6.4%	4.8	-0.1%
november	5.5	5.0	-9.2%	6.0	9.0%	5.6	2.8%	4.7	-14.3%	5.6	2.8%	5.4	-1.7%
december	6.1	5.7	-7.0%	6.8	11.6%	6.4	4.4%	5.4	-11.5%	6.5	6.2%	6.1	0.0%
january	6.2	5.9	-5.5%	7.1	13.5%	6.6	5.6%	5.7	-8.1%	6.9	10.3%	6.5	4.3%
february	6.7	6.4	-3.4%	7.7	15.9%	7.2	7.8%	6.5	-2.5%	7.8	17.0%	7.3	9.5%
average	5.9	5.5	-6.5%	6.6	12.2%	6.1	5.0%	5.3	-9.2%	6.4	8.9%	6.0	2.8%
(*) assuming wp (2000) = 1 (kg/m3)													
(**) assuming wp (2050)= wp(2000)*1.2= 1.2 (kg/m3)													

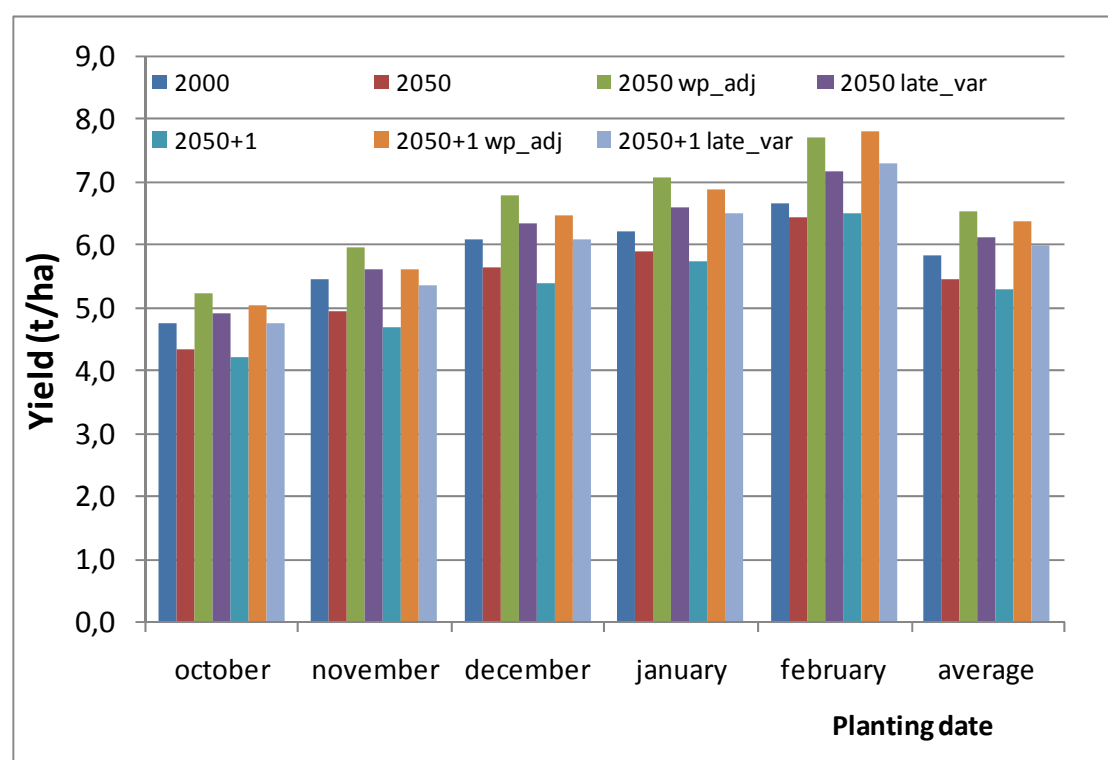
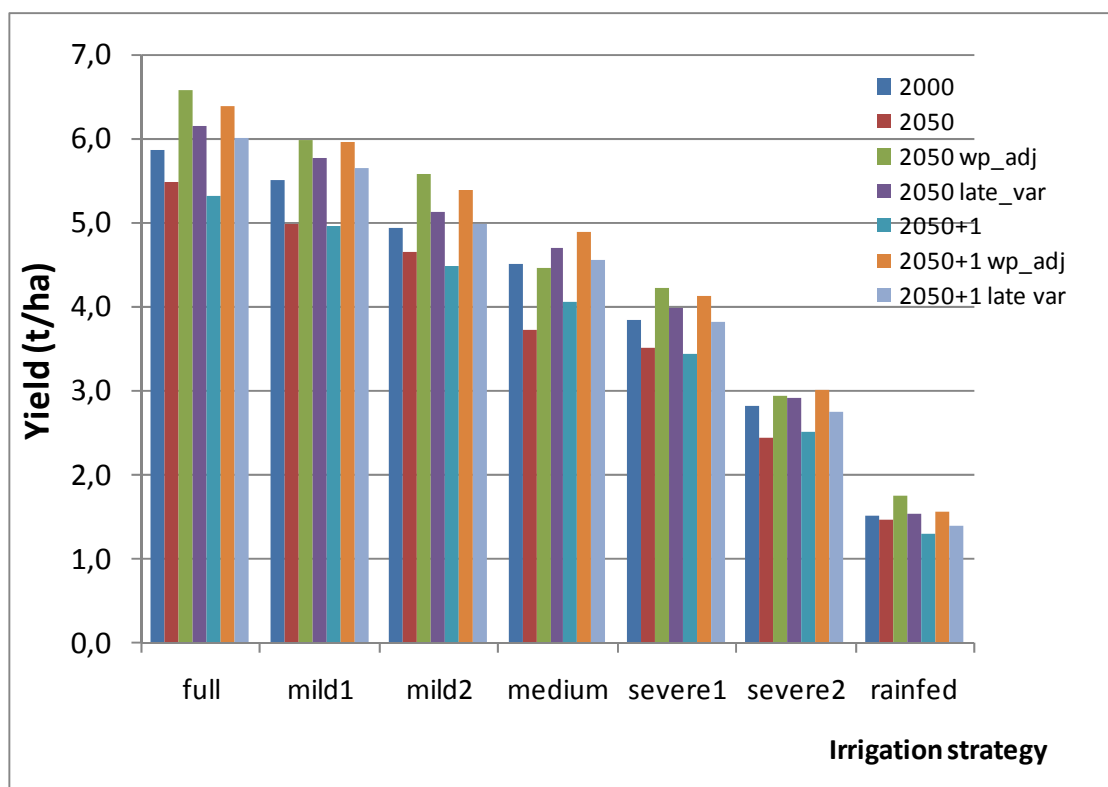


Fig. 14 – Effect of planting date, irrigation strategies, variety selection and atmospheric CO₂ increase on potential yield of wheat in Jordan river basin (Jordan) under “present”, “future” and “extreme weather (2050+1)” climate conditions.

3.3. Tomato

3.3.1. Cycle length and crop coefficient curves

The effect of temperature increase (and relative GDD accumulation) on current and projected crop cycle length and corresponding crop coefficient curves is represented in the following graphs, and the following observations have to be highlighted:

- if varietal adaptation is not considered, an important reduction of the total growing cycle is predicted for all planting dates, because of the faster accumulation of the required GGD sum under “future” climate conditions (2050) (fig. 15-16);
- if a late maturing variety will be used, the total crop cycle length (2050 late_var) is projected to remain relatively the same as for the current variety under “present” climate conditions (2000), especially for late planting dates (fig. 16);
- with respect to the four crop coefficient stages, a relative reduction is predicted in proportion to the corresponding increase in the cumulative GDD (lower during winter, higher during spring-summer months), but with a greater effect in the case of early (February) rather than late (April) planting dates (fig. 15).

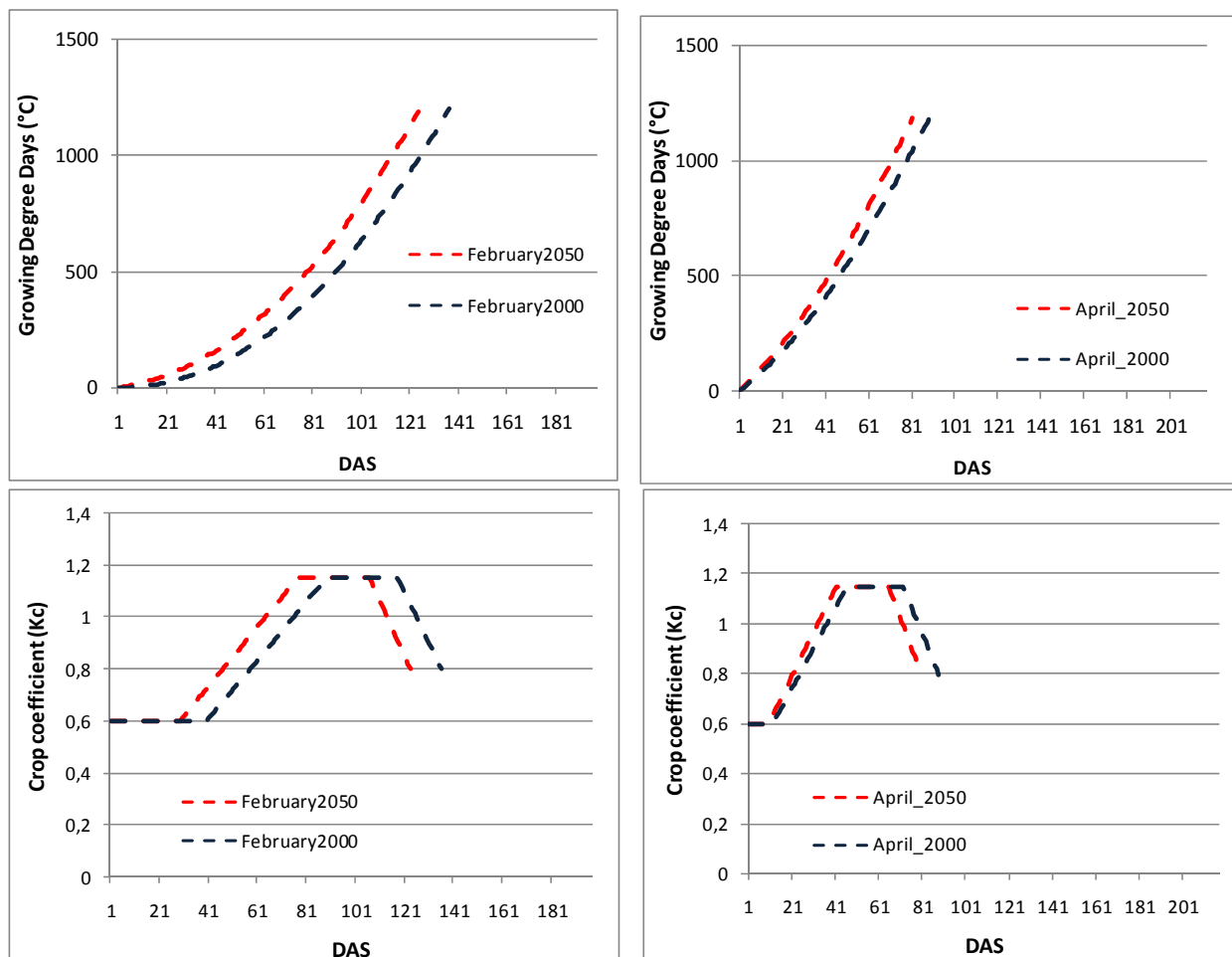


Fig. 15 – Predicted cumulative GDD and corresponding Kc curves for tomato in Jordan river basin (Jordan) as affected by different planting dates and climate scenarios.

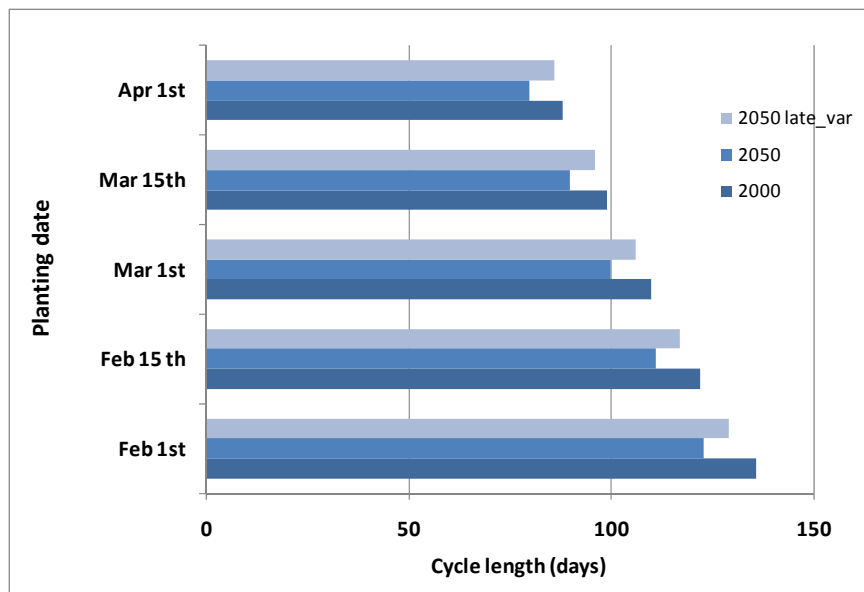


Fig. 16 – Length of total growing cycle of tomato in Jordan river basin (Jordan) as affected by planting date, variety selection and climate variations.

3.3.2. Crop evapotranspiration and irrigation requirements

The impact of climate change on maximum and effective crop evapotranspiration as well as on net irrigation requirements, also considering the relative effect of selected adaptation strategies (planting dates, variety selection and deficit irrigation strategies), is summarized in the following tables and graphs. In brief, the following observations are reported:

- maximum seasonal crop evapotranspiration is projected to reduce for the current variety under “future” (2050) scenario as a consequence of the expected shortening of the crop growing cycle, on average of about -6.8% with respect to current conditions (2000) (fig.18 and tab. 25);
- on the contrary, if a late maturing variety (2050 late_var) is selected, maximum evapotranspiration is projected to increase slightly (on average of about +1.3%) for all the planting dates (fig. 18 and tab. 25);
- the relative effect of the projected variation of rainfall patterns seems to be irrelevant for the crop water balance, because of their very low values (tab.26);
- maximum seasonal crop evapotranspiration is observed always to decrease slightly (in absolute terms) for late (April) planting date with respect to earlier (February) ones, because of the effect of higher summer temperatures in reducing the crop growing cycle (fig. 18 and tab. 25);
- effective seasonal crop evapotranspiration and net irrigation requirements are both highly dependent on the irrigation strategy, progressively reducing going from full irrigation to rainfed conditions (fig. 18 and tab.27-28);
- as for ET_{c_max} , also the ET_{c_eff} and NIR are projected to decrease in 2050 if the current variety is used; on the other side, if a late maturing variety is selected, NIR and ET_{c_eff} variations seems to be very slight, depending somehow on the irrigation strategy considered (fig. 18 and tab.27-28);

Tab.25 – Effect of planting date and variety selection on the maximum crop evapotranspiration of tomato in Jordan river basin (Jordan) under “present” and “future” climate conditions.

Planting date	ETc_max 2000	ETc_max 2050		ETc_max 2050 late_var	
	[mm/season]	[mm/season]	(variation vs 2000)	[mm/season]	(variation vs 2000)
February 1st	710.9	654.7	-7.9%	706.2	-0.7%
February 15th	682.0	637.1	-6.6%	688.9	1.0%
March 1st	663.2	619.0	-6.7%	672.7	1.4%
March 15th	640.8	599.7	-6.4%	654.3	2.1%
April 1st	622.3	584.0	-6.1%	640.7	3.0%
average	663.8	618.9	-6.8%	672.6	1.3%

Tab. 26 – Effect of planting date and variety selection on the effective rainfall pattern during crop cycle of tomato in Jordan river basin (Jordan) under “present” and “future” climate conditions.

Planting date	Rain_eff 2000	Rain_eff 2050		Rain_eff 2050 late_var	
	[mm/season]	[mm/season]	(variation vs 2000)	[mm/season]	(variation vs 2000)
February 1st	32.3	36.6	13.3%	36.6	13.3%
February 15th	25.4	25.8	1.8%	25.8	1.8%
March 1st	20.9	23.1	10.8%	23.1	10.8%
March 15th	17.7	19.2	7.9%	19.2	7.9%
April 1st	9.2	9.9	7.5%	9.9	7.5%
average	21.1	22.9	8.6%	22.9	8.6%

Tab. 27 – Effect of irrigation strategies and variety selection on the effective crop evapotranspiration of tomato in Jordan river basin (Jordan) under “present” and “future” climate.

Irrigation strategy	ETc_eff 2000	ETc_eff 2050		ETc_eff 2050 late_var	
	[mm/season]	[mm/season]	(variation vs 2000)	[mm/season]	(variation vs 2000)
full	662.6	617.8	-6.8%	671.3	1.3%
mild1	631.3	588.9	-6.7%	638.2	1.1%
mild2	570.1	534.0	-6.3%	576.8	1.2%
medium	549.7	514.4	-6.4%	558.0	1.5%
severe1	462.6	435.1	-5.9%	467.3	1.0%
severe2	346.9	329.3	-5.1%	351.1	1.2%
rainfed	143.3	143.3	0.0%	143.4	0.1%

Tab. 28 – Effect of irrigation strategies and variety selection on the net irrigation requirements of tomato in Jordan river basin (Jordan) under “present” and “future” climate conditions.

Irrigation strategy	NIR 2000	NIR 2050		NIR 2050 late_var	
	[mm/season]	[mm/season]	(variation vs 2000)	[mm/season]	(variation vs 2000)
full	611.8	569.9	-6.9%	629.3	2.9%
mild1	569.0	523.4	-8.0%	570.9	0.3%
mild2	489.4	455.9	-6.9%	503.4	2.9%
medium	465.1	425.6	-8.5%	483.6	4.0%
severe1	369.8	340.2	-8.0%	371.1	0.3%
severe2	232.5	212.8	-8.5%	241.8	4.0%
rainfed	0.0	0.0	0.0%	0.0	0.0%

- by plotting together the values of seasonal ETc_{eff} and NIR (obtained under different irrigation strategies and variety) for different climate scenarios, there is a clear prediction of their reduction (respectively of about -6.4% and -7.6%, on average) while, by considering a late maturing variety, only a slight increase of both is predicted (respectively of about +1.1% and +2%, on average) (fig. 17);
- the cumulative curves of ETc_{max} in 2050 (versus 2000) show always (especially for earlier planting dates) a clear shifting towards higher values, thus representing the relative increase in the daily crop water requirements, although with a decrease in the cumulative final value (depending on the anticipated ending of the cycle) (fig. 19).

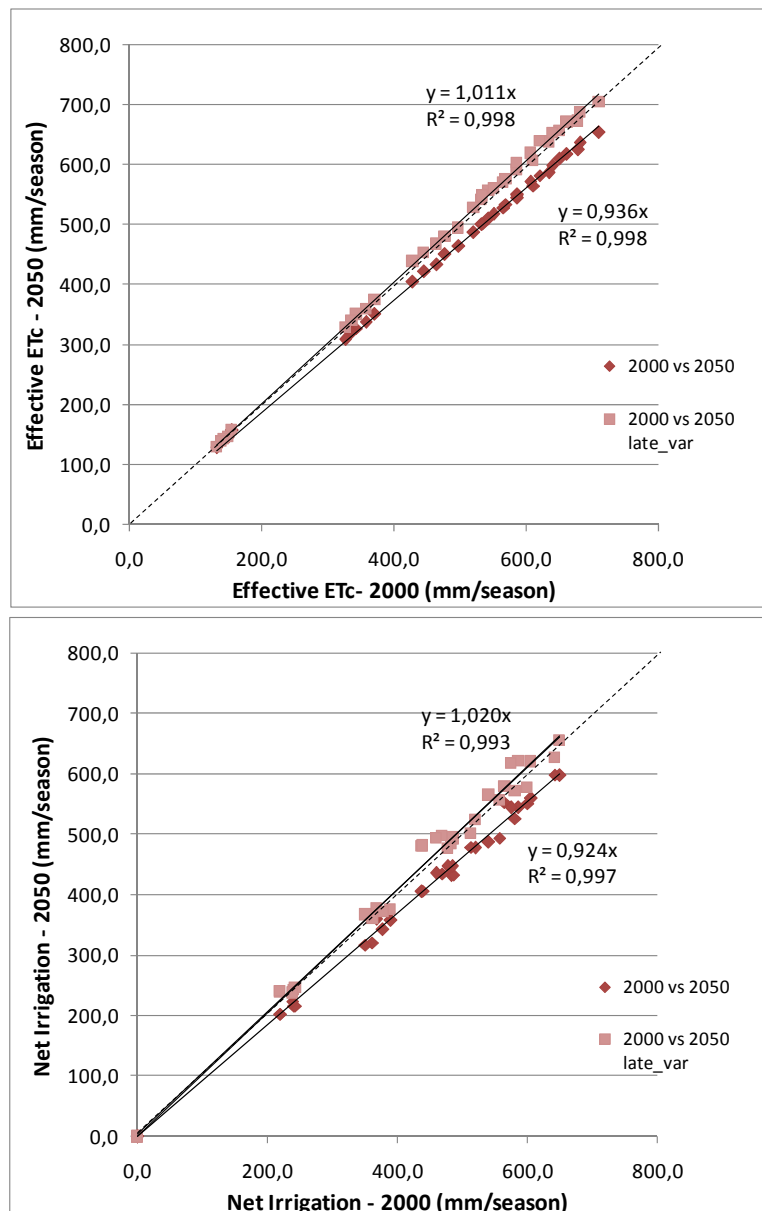


Fig. 17 – Scatter-plot of seasonal crop evapotranspiration and net irrigation requirements of as affected by different variety selection for tomato in Jordan river basin (Jordan) under “present” and “future” climate conditions.

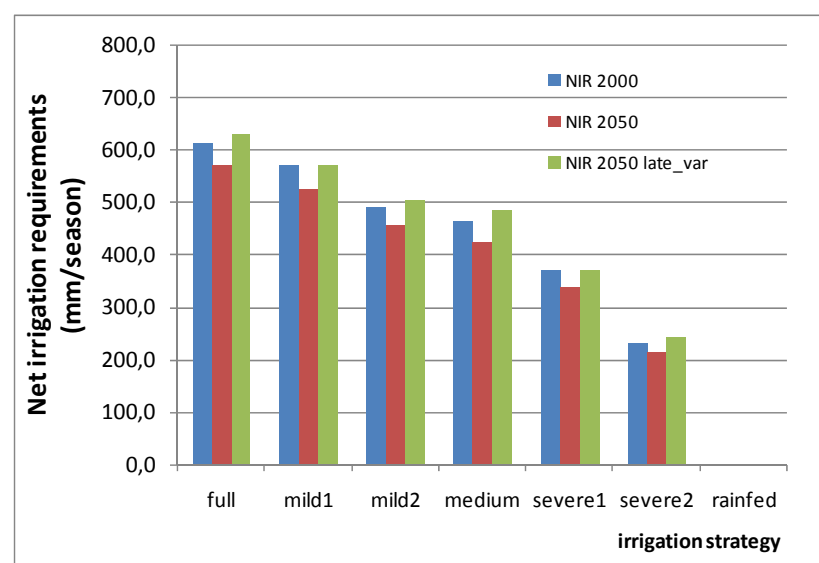
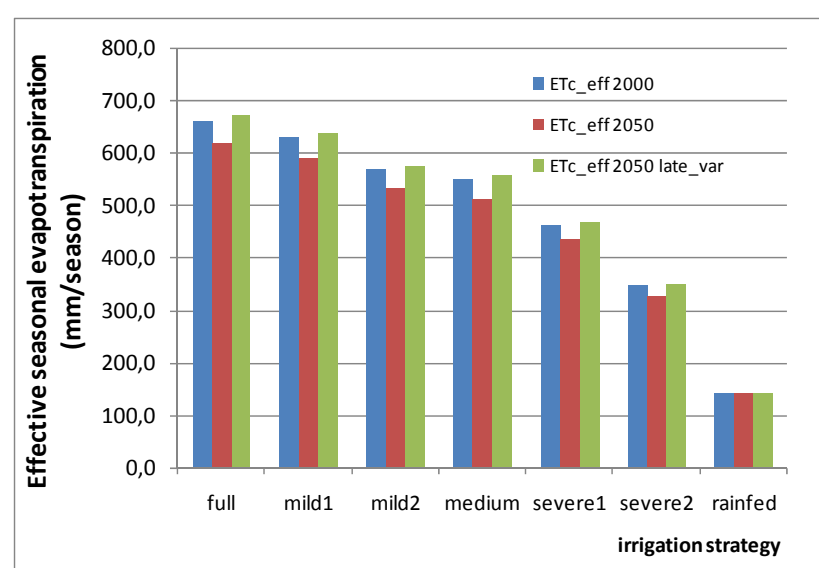
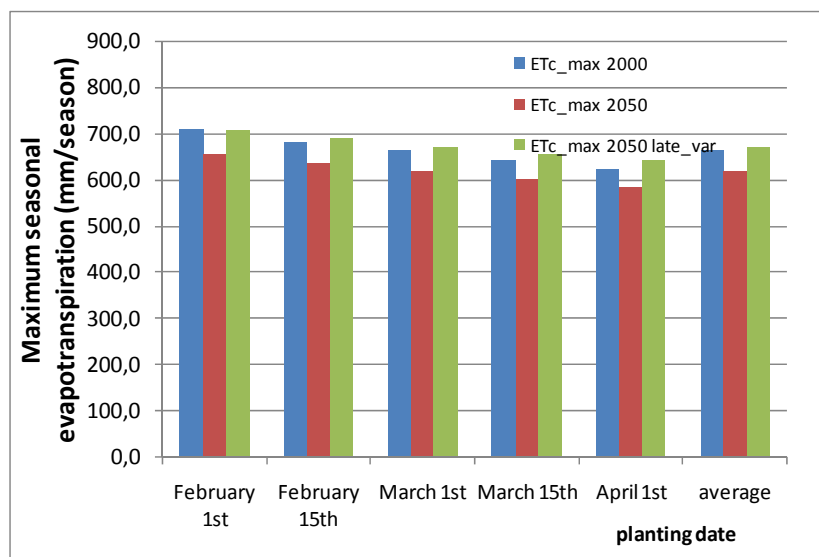


Fig. 18 – Effect of planting date, irrigation strategies and variety selection on maximum and effective crop evapotranspiration and net irrigation requirements of tomato in Jordan river basin (Jordan) under “present” and “future” climate conditions.

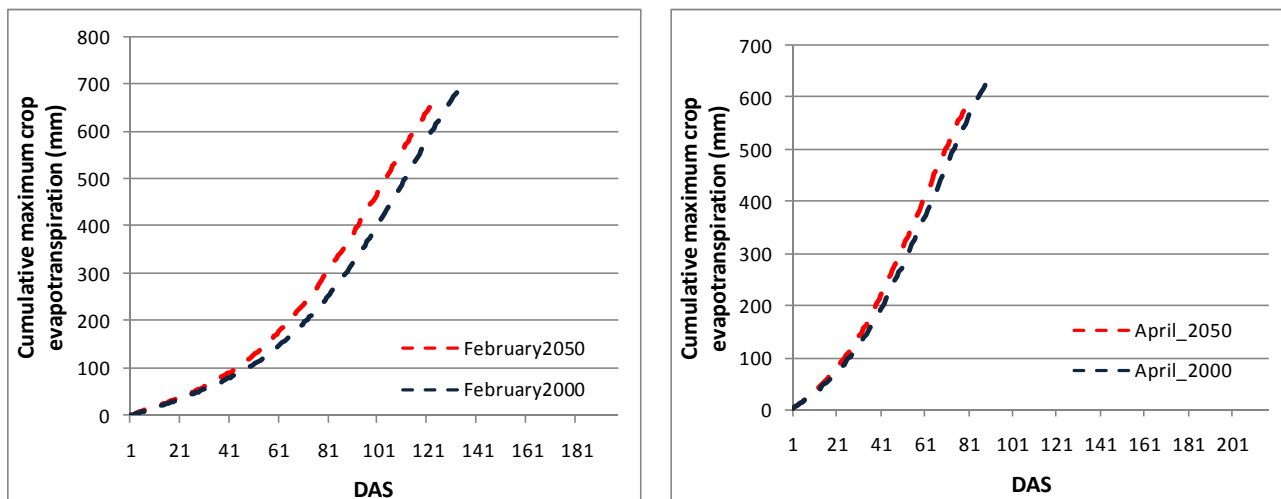


Fig. 19 – Cumulative curves of maximum crop evapotranspiration as affected by different planting date for tomato in Jordan river basin (Jordan) under “present” and “future” climate conditions.

3.3.3. Yield response to water

The impact of climate change on potential yield, also considering the relative effect of selected adaptation strategies (planting dates, variety selection and deficit irrigation strategies), is summarized in the following tables and graphs. In brief, the following observations are reported:

- maximum yield is projected to reduce under “future” scenario (2050) with respect to current conditions (2000), on average from 66.4 to 61.9 t ha⁻¹ (about -6.8%), depending on irrigation strategies (tab. 29 and fig.20) and planting dates (tab. 30 and fig. 20) as a consequence of the expected shortening of the crop growing cycle;
- on the contrary, if the expected fertilizing effect due to an increase in atmospheric CO₂ concentration will occur, yield (2050 wp_adj) is projected to increase in quite all conditions (with an average of 74.3 t ha⁻¹, +11.9%), and thus to overcome the effect of the shortening of the crop cycle (fig. 20 and tab.29-30);
- on the other side, if a late maturing variety (2050 late_var) is selected, yield is projected to increase (with an average of 67.3 t ha⁻¹, +1.3%), especially under fully irrigation and late planting dates (fig. 20 and tab. 29-30);
- there is a clear reduction in potential yield under increasing water stress conditions (fig.), but still under “severe” water stress (thus only supported by supplemental irrigations) values of 12-30 t ha⁻¹ are still possible to be reached; in the case of rainfed conditions, according to the model used, no yield is expected in all conditions;
- yield is observed to slightly decrease (in absolute terms) for late (April) planting date with respect to earlier (February) ones (fig.20), because of the shortening of the growing cycle due to its shifting in the hotter summer.

Tab. 29 – Effect of irrigation strategies, variety selection and atmospheric CO₂ increase on the potential yield of tomato in Jordan river basin (Jordan) under “present” and “future” climate conditions.

Irrigation strategy	Yield 2000 (*)	Yield 2050 (*)		Yield 2050 wp_adj (**)		Yield 2050 late_var (*)	
	(t/ha)	(t/ha)	(variation vs 2000)	(t/ha)	(variation vs 2000)	(t/ha)	(variation vs 2000)
full	66.4	61.9	-6.8%	74.3	11.9%	67.3	1.3%
mild1	59.1	55.3	-6.5%	66.4	12.2%	59.7	1.0%
mild2	44.1	41.8	-5.4%	50.1	13.6%	44.9	1.8%
medium	44.5	41.6	-6.4%	49.9	12.3%	44.7	0.5%
severe1	26.8	25.8	-3.9%	30.9	15.4%	27.4	2.1%
severe2	13.7	13.5	-1.8%	16.2	17.8%	14.0	2.0%
rainfed	0.0	0.0		0.0		0.0	
(*) assuming wp (2000) = 10 (kg/m3)							
(**) assuming wp (2050)= wp(2000)*1.2= 12 (kg/m3)							

Tab. 30 – Effect of planting date, variety selection and atmospheric CO₂ increase on the potential yield of tomato in Jordan river basin (Jordan) under “present” and “future” climate conditions.

Irrigation strategy	Yield 2000 (*)	Yield 2050 (*)		Yield 2050 wp_adj (**)		Yield 2050 late_var (*)	
	(t/ha)	(t/ha)	(variation vs 2000)	(t/ha)	(variation vs 2000)	(t/ha)	(variation vs 2000)
February 1st	71.1	65.5	-7.9%	78.6	10.5%	70.6	-0.7%
Febr 15th	68.2	63.7	-6.6%	76.5	12.1%	68.9	1.0%
March 1st	66.3	61.9	-6.7%	74.3	12.0%	67.3	1.4%
March 15th	64.1	60.0	-6.4%	72.0	12.3%	65.4	2.1%
April 1st	62.2	58.4	-6.1%	70.1	12.6%	64.1	3.0%
average	66.4	61.9	-6.8%	74.3	11.9%	67.3	1.3%
(*) assuming wp (2000) = 10 (kg/m3)							
(**) assuming wp (2050)= wp(2000)*1.2= 12 (kg/m3)							

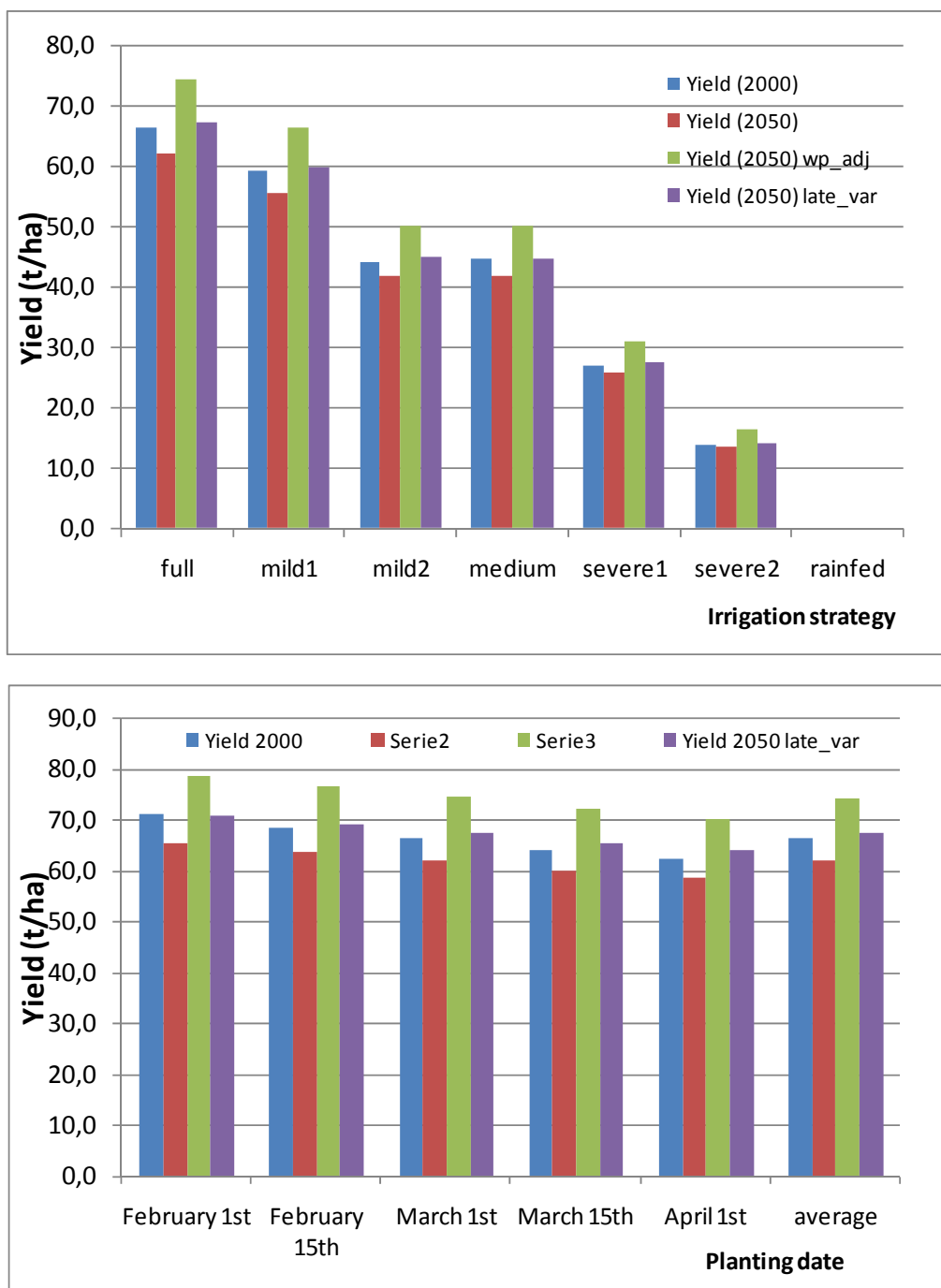


Fig. 20 – Effect of planting date, irrigation strategies, variety selection and atmospheric CO₂ increase on potential yield of tomato in Jordan river basin (Jordan) under “present” and “future” climate conditions.

3.4. Potato

3.4.1. Cycle length and crop coefficient curves

The effect of temperature increase (and relative GDD accumulation) on current and projected crop cycle length and corresponding crop coefficient curves is represented in the following graphs, and the following observations have to be highlighted:

- if varietal adaptation is not considered, an important reduction of the total growing cycle is predicted for all planting dates, because of the faster accumulation of the required GGD sum under “future” climate conditions (2050) (fig. 21-22);
- if a late maturing variety will be used, the total crop cycle length (2050 late_var) is projected to remain relatively the same as for the current variety under “present” climate conditions (2000), especially for late planting dates (fig. 22);
- with respect to the four crop coefficient stages, a relative reduction is predicted in proportion to the corresponding increase in the cumulative GDD (lower during winter, higher during spring-summer months), but with a greater effect in the case of early (October) rather than late (February) planting dates (fig. 21).

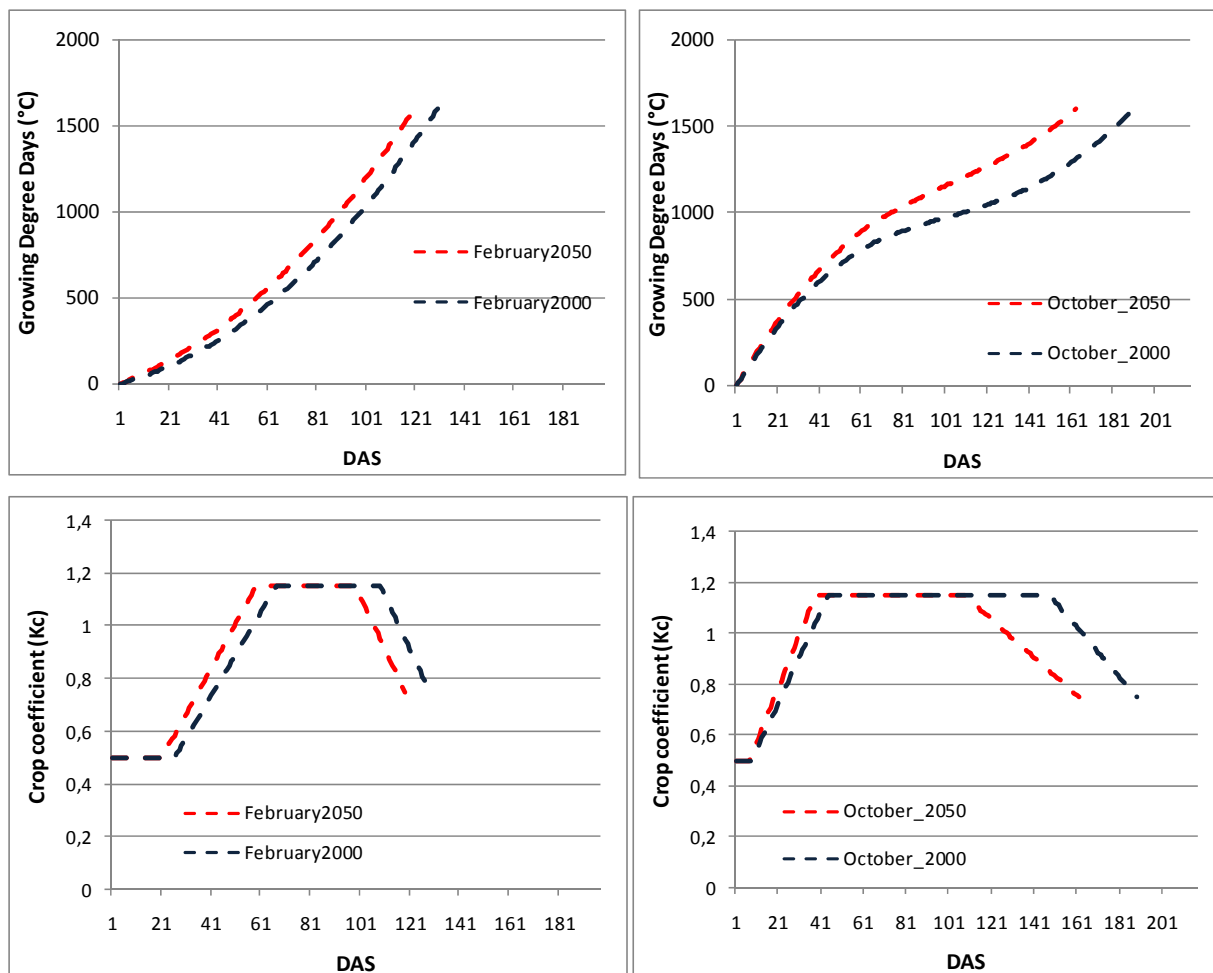


Fig. 21 – Predicted cumulative GDD and corresponding Kc curves for potato in Jordan river basin (Jordan) as affected by different planting dates and climate scenarios.

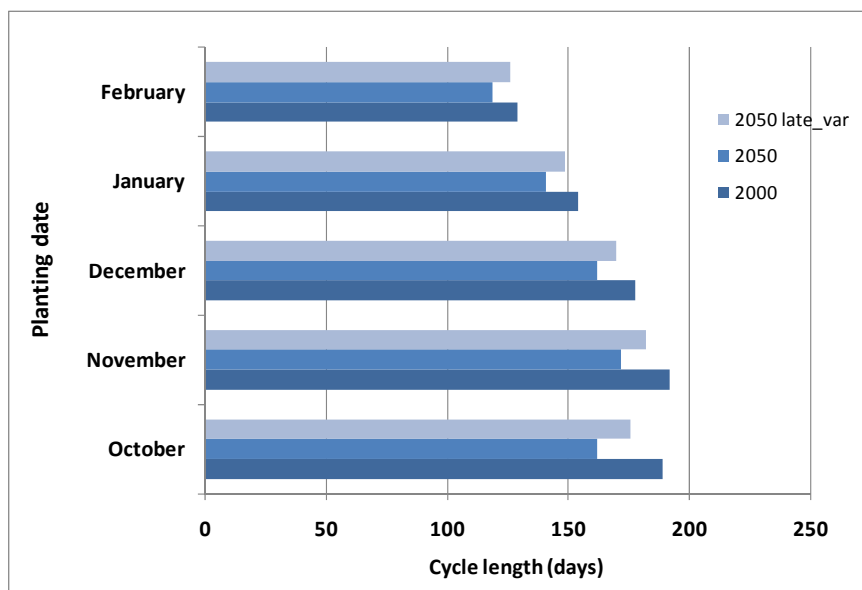


Fig. 22 – Length of total growing cycle of potato in Jordan river basin (Jordan) as affected by planting date, variety selection and climate variations.

3.4.2. Crop evapotranspiration and irrigation requirements

The impact of climate change on maximum and effective crop evapotranspiration as well as on net irrigation requirements, also considering the relative effect of selected adaptation strategies (planting dates, variety selection and deficit irrigation strategies), is summarized in the following tables and graphs. In brief, the following observations are reported:

- maximum seasonal crop evapotranspiration is projected to reduce for the current variety under “future” (2050) scenario as a consequence of the expected shortening of the crop growing cycle, on average of about -10.3% with respect to current conditions (2000) (fig. 24 and tab. 31);
- on the contrary, if a late maturing variety (2050 late_var) is selected, maximum evapotranspiration is projected to remain almost the same (on average of about -0.7%) (fig. 24 and tab. 31);
- the relative effect of the projected variation of rainfall patterns seems slightly important for the crop water balance, with an average reduction of about -2.2 mm during cropping cycle (tab. 32);
- maximum seasonal crop evapotranspiration is observed always to increase (in absolute terms) for late (February) planting date with respect to earlier (October) ones, because of the shifting of most of the cycle towards the higher spring-summer temperatures and the corresponding reduction in the total length (fig. 24 and tab.31);
- effective seasonal crop evapotranspiration and net irrigation requirements are both highly dependent on the irrigation strategy, progressively reducing going from full irrigation to rainfed conditions (fig. 24 and tab.33-34);
- as for ET_{c_max} , also the ET_{c_eff} and NIR are projected to decrease in 2050 if the current variety is used; on the other side, if a late maturing variety is selected, NIR and ET_{c_eff} are always projected to remain relatively stable or slightly reduce (fig. 24 and tab. 33-34);

Tab.31 – Effect of planting date and variety selection on the maximum crop evapotranspiration of potato in Jordan river basin (Jordan) under “present” and “future” climate conditions.

Planting date	ETc_max 2000	ETc_max 2050		ETc_max 2050 late_var	
	[mm/season]	[mm/season]	(variation vs 2000)	[mm/season]	(variation vs 2000)
october	591.7	492.1	-16.8%	557.9	-5.7%
november	668.2	584.5	-12.5%	649.6	-2.8%
december	694.8	626.7	-9.8%	688.1	-1.0%
january	661.8	613.3	-7.3%	676.7	2.3%
february	665.5	627.1	-5.8%	686.6	3.2%
average	656.4	588.7	-10.3%	651.8	-0.7%

Tab.32– Effect of planting date and variety selection on the effective rainfall pattern during crop cycle of potato in Jordan river basin (Jordan) under “present” and “future” climate conditions.

Planting date	Rain_eff 2000	Rain_eff 2050		Rain_eff 2050 late_var	
	[mm/season]	[mm/season]	(variation vs 2000)	[mm/season]	(variation vs 2000)
october	89.7	79.9	-10.9%	85.2	-5.0%
november	87.0	81.8	-6.0%	84.8	-2.6%
december	68.4	66.8	-2.4%	66.8	-2.4%
january	41.0	42.5	3.7%	42.5	3.7%
february	32.3	36.6	13.3%	36.6	13.3%
average	63.7	61.5	-3.4%	63.2	-0.8%

Tab. 33 – Effect of irrigation strategies and variety selection on the effective crop evapotranspiration of potato in Jordan river basin (Jordan) under “present” and “future” climate.

Irrigation strategy	ETc_eff 2000	ETc_eff 2050		ETc_eff 2050 late_var	
	[mm/season]	[mm/season]	(variation vs 2000)	[mm/season]	(variation vs 2000)
full	654.6	587.4	-10.3%	650.1	-0.7%
mild1	612.9	551.5	-10.0%	608.2	-0.8%
mild2	557.5	502.9	-9.8%	553.1	-0.8%
medium	536.6	482.6	-10.1%	532.5	-0.8%
severe1	447.9	406.3	-9.3%	443.8	-0.9%
severe2	338.2	308.7	-8.7%	334.7	-1.0%
rainfed	139.7	134.7	-3.5%	136.7	-2.1%

Tab.34 – Effect of irrigation strategies and variety selection on the net irrigation requirements of potato in Jordan river basin (Jordan) under “present” and “future” climate conditions.

Irrigation strategy	NIR 2000	NIR 2050		NIR 2050 late_var	
	[mm/season]	[mm/season]	(variation vs 2000)	[mm/season]	(variation vs 2000)
full	579.0	512.4	-11.5%	572.5	-1.1%
mild1	527.4	470.4	-10.8%	525.9	-0.3%
mild2	463.2	409.9	-11.5%	458.0	-1.1%
medium	433.2	393.7	-9.1%	434.8	0.4%
severe1	342.8	305.7	-10.8%	341.8	-0.3%
severe2	216.6	196.9	-9.1%	217.4	0.4%
rainfed	0.0	0.0	0.0%	0.0	0.0%

- by plotting together the values of seasonal ETc_{eff} and NIR (obtained under different irrigation strategies and variety) for different climate scenarios, there is a clear prediction of their reduction (respectively of about -9.8% and -10.6%, on average) and, also by considering a late maturing variety, a relative stability or slight decrease of both is predicted (respectively of about -0.8% and -0.4%, on average) (fig.23);
- the cumulative curves of ETc_{max} in 2050 (versus 2000) show always a clear shifting towards higher values, thus representing the relative increase in the daily crop water requirements, although with a decrease in the cumulative final value (depending on the anticipated ending of the cycle) (fig.25).

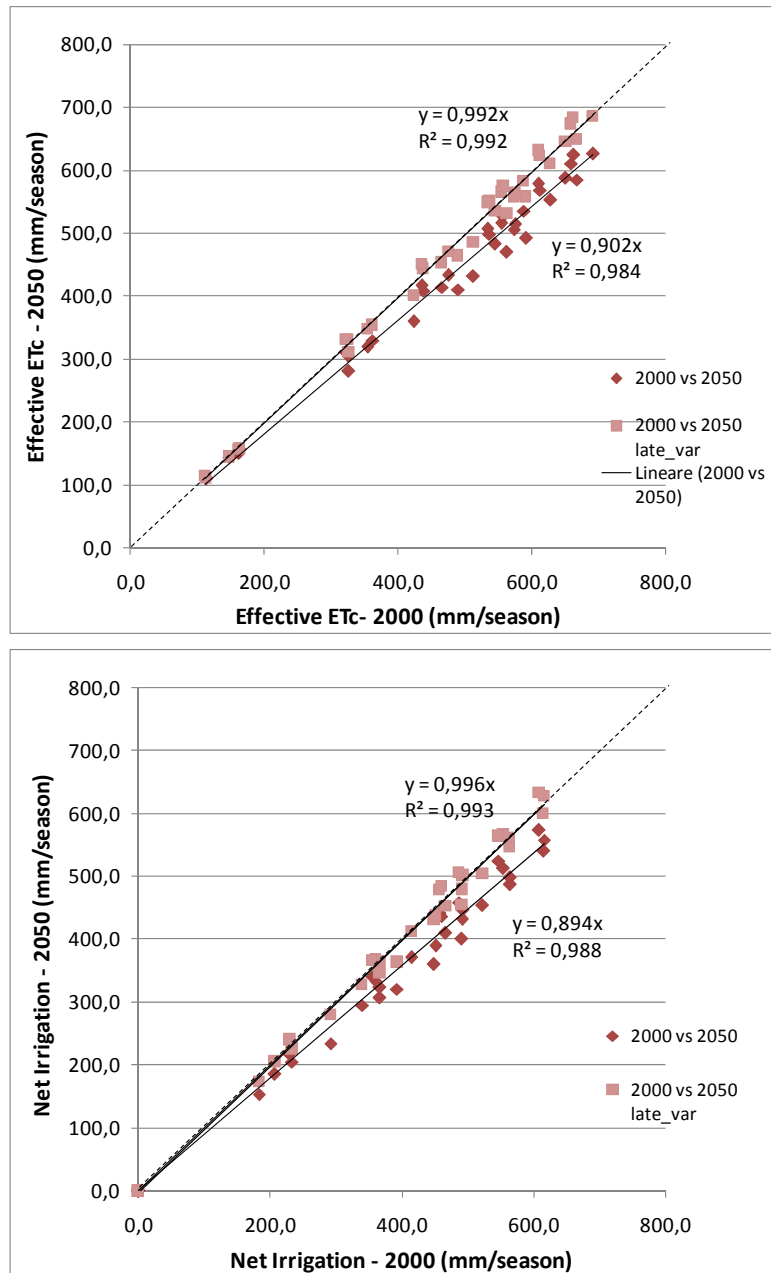


Fig. 23 – Scatter-plot of seasonal crop evapotranspiration and net irrigation requirements of as affected by different variety selection for potato in Jordan river basin (Jordan) under “present” and “future” climate conditions.

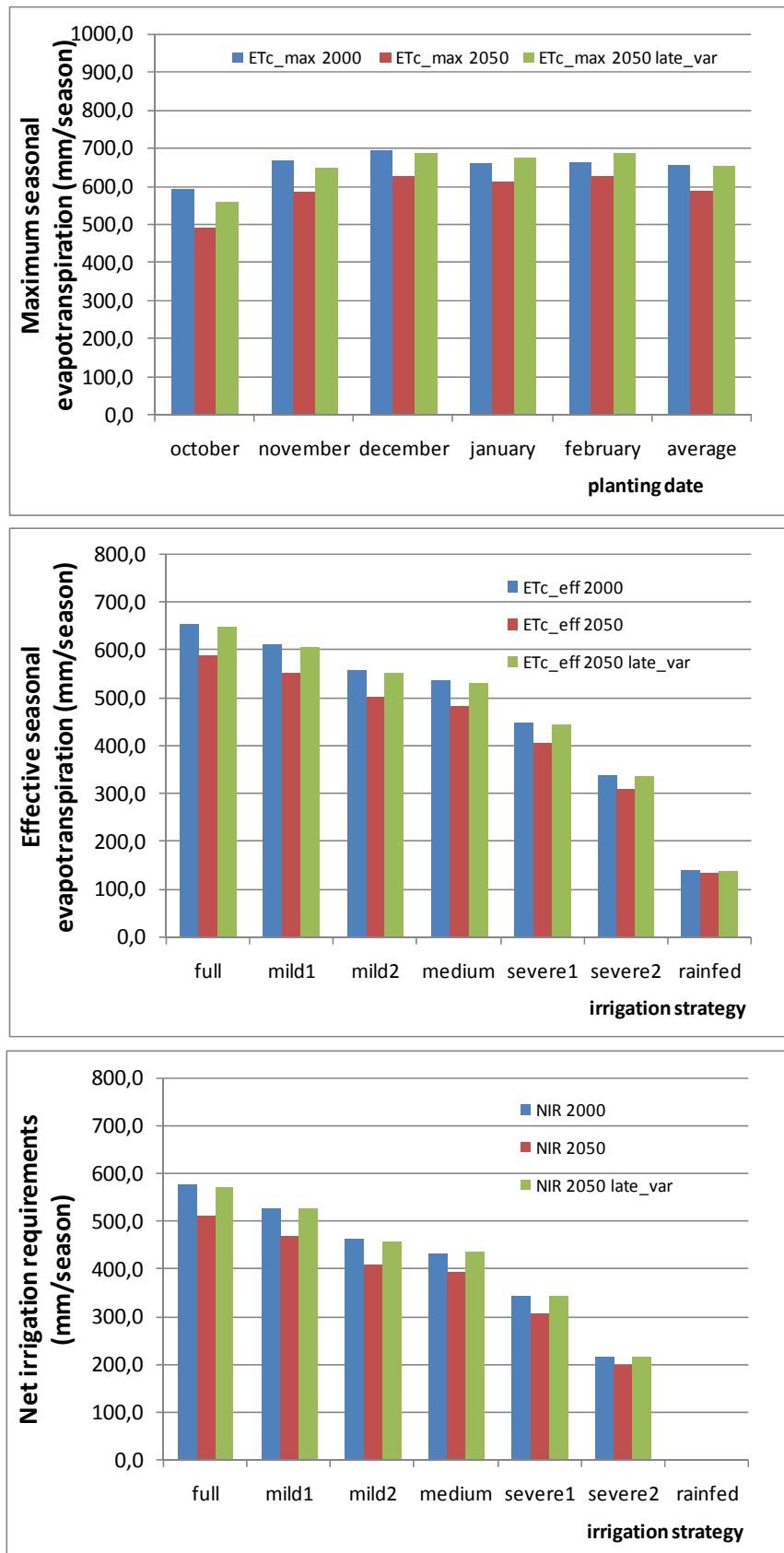


Fig. 24 – Effect of planting date, irrigation strategies and variety selection on maximum and effective crop evapotranspiration and net irrigation requirements of potato in Jordan river basin (Jordan) under “present” and “future” climate conditions.

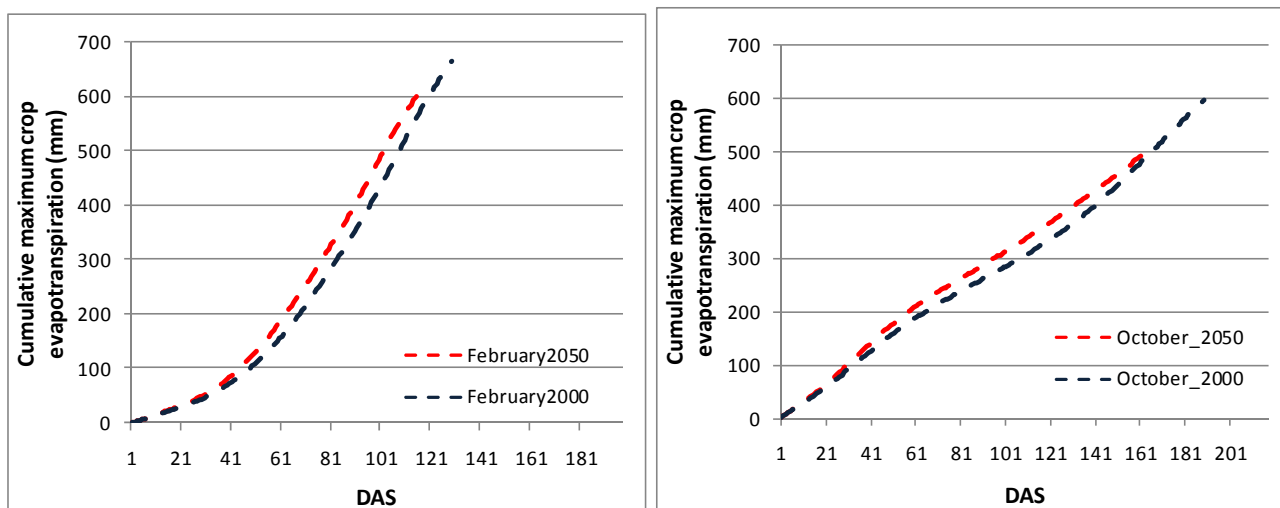


Fig. 25 – Cumulative curves of maximum crop evapotranspiration as affected by different planting date for potato in Jordan river basin (Jordan) under “present” and “future” climate conditions.

3.4.3. Yield response to water

The impact of climate change on potential yield, also considering the relative effect of selected adaptation strategies (planting dates, variety selection and deficit irrigation strategies), is summarized in the following tables and graphs. In brief, the following observations are reported:

- maximum yield is projected to reduce under “future” scenario (2050) with respect to current conditions (2000), on average from 32.8 to 29.4 t ha⁻¹ (about -10.3%), depending on irrigation strategies (tab. 35 and fig. 26) and planting dates (tab. 36 and fig. 26) as a consequence of the expected shortening of the crop growing cycle;
- on the contrary, if the expected fertilizing effect due to an increase in atmospheric CO₂ concentration will occur, yield (2050 wp_adj) is projected to increase in quite all conditions (with an average of 35.3 t ha⁻¹, +7.6%), and thus to overcome the effect of the shortening of the crop cycle (fig. 26 and tab.35-36);
- on the other side, if a late maturing variety (2050 late_var) is selected, yield is projected to remain stable or slightly increase (with an average of 32.6 t ha⁻¹, -0.7%), depending on irrigation strategy and planting dates (fig. 26 and tab.35-36);
- there is a clear reduction in potential yield under increasing water stress conditions (fig.26), and under “severe” water stress (thus only supported by supplemental irrigations) values of 12-20 t ha⁻¹ are predicted; in the case of rainfed conditions, very low yield (around 6 t ha⁻¹) is expected in all conditions;
- yield is observed always to increase (in absolute terms) for late (February) planting date with respect to earlier (October) ones (fig.26), because of the corresponding increase in total maximum crop evapotranspiration.

Tab. 35 – Effect of irrigation strategies, variety selection and atmospheric CO₂ increase on the potential yield of potato in Jordan river basin (Jordan) under “present” and “future” climate conditions.

Irrigation strategy	Yield 2000 (*) (t/ha)	Yield 2050 (*)		Yield 2050 wp_adj (**)		Yield 2050 late_var (*)	
		(t/ha)	(variation vs 2000)	(t/ha)	(variation vs 2000)	(t/ha)	(variation vs 2000)
full	32.8	29.4	-10.3%	35.3	7.6%	32.6	-0.7%
mild1	29.9	27.0	-9.7%	32.4	8.4%	29.7	-0.6%
mild2	26.0	23.8	-8.5%	28.6	9.8%	26.0	0.0%
medium	24.5	22.3	-8.9%	26.8	9.4%	24.5	-0.1%
severe1	19.0	17.7	-7.1%	21.2	11.5%	19.1	0.4%
severe2	13.2	12.5	-5.3%	15.0	13.6%	13.4	1.1%
rainfed	5.7	5.8	0.9%	6.9	21.1%	5.9	2.9%
(*) assuming wp (2000) = 5 (kg/m3)							
(**) assuming wp (2050)= wp(2000)*1.2= 6 (kg/m3)							

Tab. 36 – Effect of planting date, variety selection and atmospheric CO₂ increase on the potential yield of potato in Jordan river basin (Jordan) under “present” and “future” climate conditions.

Irrigation strategy	Yield 2000 (*) (t/ha)	Yield 2050 (*)		Yield 2050 wp_adj (**)		Yield 2050 late_var (*)	
		(t/ha)	(variation vs 2000)	(t/ha)	(variation vs 2000)	(t/ha)	(variation vs 2000)
october	29.6	24.6	-16.8%	29.5	-0.2%	27.9	-5.7%
november	33.4	29.2	-12.5%	35.1	5.0%	32.5	-2.8%
december	34.7	31.3	-9.8%	37.6	8.3%	34.4	-1.0%
january	33.1	30.7	-7.3%	36.8	11.2%	33.8	2.3%
february	33.3	31.4	-5.8%	37.6	13.1%	34.3	3.2%
average	32.8	29.4	-10.3%	35.3	7.6%	32.6	-0.7%
(*) assuming wp (2000) = 5 (kg/m3)							
(**) assuming wp (2050)= wp(2000)*1.2= 6 (kg/m3)							

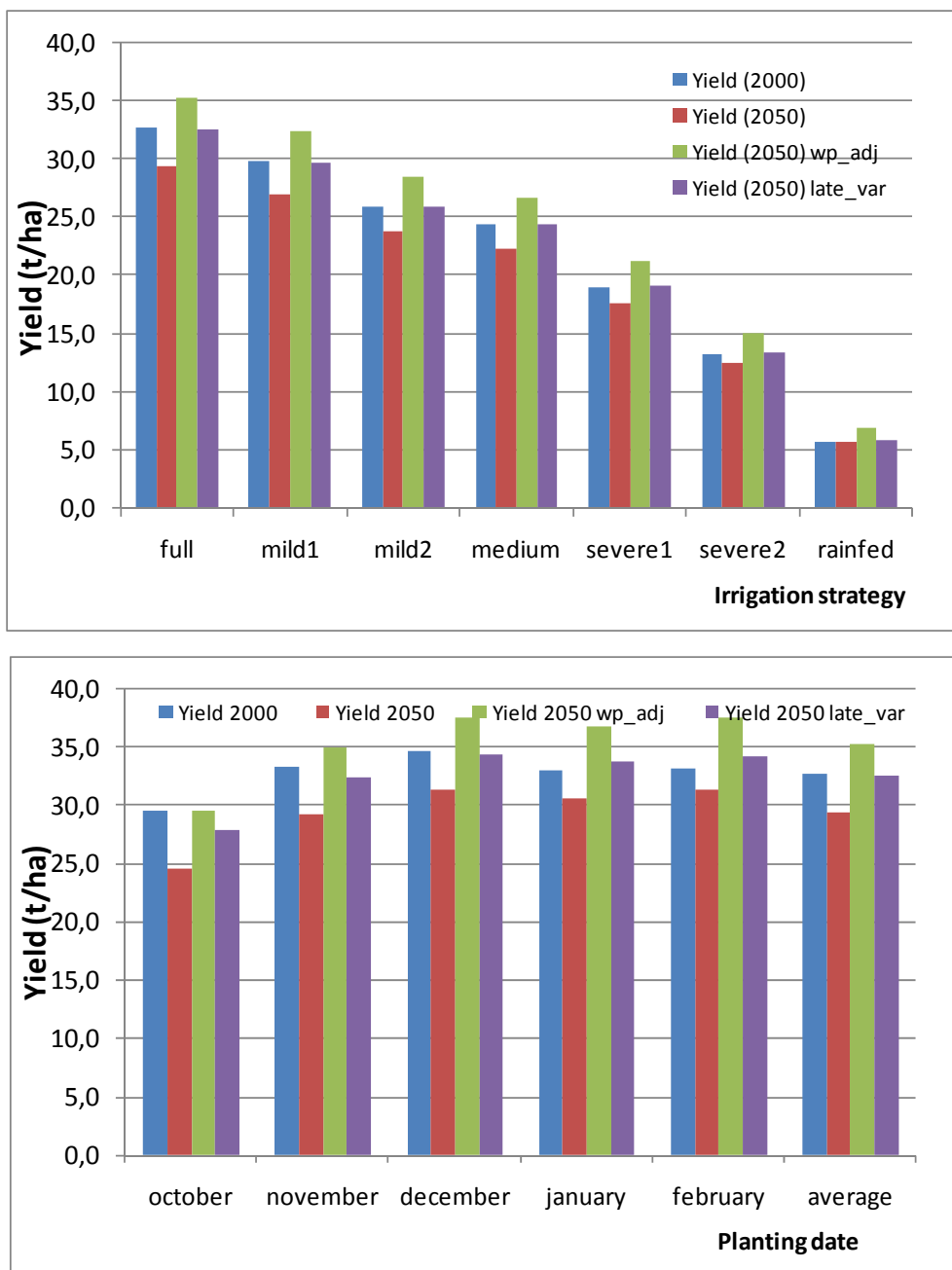


Fig. 26 – Effect of planting date, irrigation strategies, variety selection and atmospheric CO₂ increase on potential yield of potato in Jordan river basin (Jordan) under “present” and “future” climate conditions.

3.5. Olive

3.5.1. Cycle length and crop coefficient curves

The effect of temperature increase (and relative GDD accumulation) on current and projected crop cycle of olive has not been evaluated, because of the lack of sufficient information and data to model the relative length of the stages. Thus, a fixed length of the stages and of total growing period has been considered (270 days), as suggested by FAO (2012).

The crop coefficient curves have been modelled by computing the average monthly K_c values according to Orgaz et al. (2006) and FAO (2012) under the different conditions of selected climate scenarios, as affected by the changing of monthly ET_o and rainfall pattern and especially of their relative effect on the evaporative K_c components (from soil and canopy). In table 37, a comparison of the main K_c components is reported, showing the relative reduction of the canopy direct evaporative component (K_{pd}) and of the soil evaporation component ($K_{s,e}$) during the autumn to winter months, due to the projected relative decrease in rainfall pattern and increase in reference evapotranspiration.

In the figure 27, the monthly trends of crop coefficients under different climate scenarios are reported, as computed according to Orgaz et. (2006) for a “new” and an “old” type of olive crop plantation, and in comparison to the fixed K_c coefficient suggested by FAO (2012) for an arid environment; the following observations are reported:

- there is a clear effect of the type of plantation on K_c values, being higher for “new” types of cropping systems under all climate scenarios;
- as yet mentioned, the K_c values for autumn-winter months progressively reduce because of the reduction in projected ET_o and rainfall patterns;
- only slight variations are observed during the spring-summer months, where the K_{pd} and $K_{s,e}$ components reduce close to zero and no variations are observed between scenarios.

Tab. 37 - Comparison of monthly K_c values and main components for olive in Jordan river basin (Jordan) under “present”, “future” and “extreme weather” climate conditions.

Month	Kc			Kc.tr	Kpd			Ks.e		
	2000	2050	2050+1	Avg	2000	2050	2050+1	2000	2050	2050+1
1	0.80	0.65	0.59	0.26	0.09	0.05	0.04	0.39	0.28	0.24
2	0.61	0.61	0.56	0.27	0.04	0.04	0.03	0.23	0.23	0.19
3	0.51	0.52	0.49	0.29	0.02	0.03	0.02	0.14	0.14	0.12
4	0.50	0.47	0.45	0.33	0.02	0.01	0.01	0.09	0.07	0.05
5	0.45	0.45	0.45	0.38	0.01	0.00	0.00	0.00	0.00	0.00
6	0.52	0.52	0.52	0.46	0.00	0.00	0.00	0.00	0.00	0.00
7	0.52	0.52	0.52	0.46	0.00	0.00	0.00	0.00	0.00	0.00
8	0.50	0.51	0.50	0.44	0.01	0.01	0.01	0.00	0.00	0.00
9	0.52	0.49	0.47	0.40	0.01	0.01	0.01	0.05	0.02	0.01
10	0.67	0.68	0.64	0.44	0.03	0.03	0.02	0.15	0.15	0.12
11	0.81	0.80	0.73	0.40	0.06	0.06	0.04	0.29	0.28	0.23
12	0.81	0.79	0.69	0.26	0.10	0.09	0.06	0.40	0.39	0.31

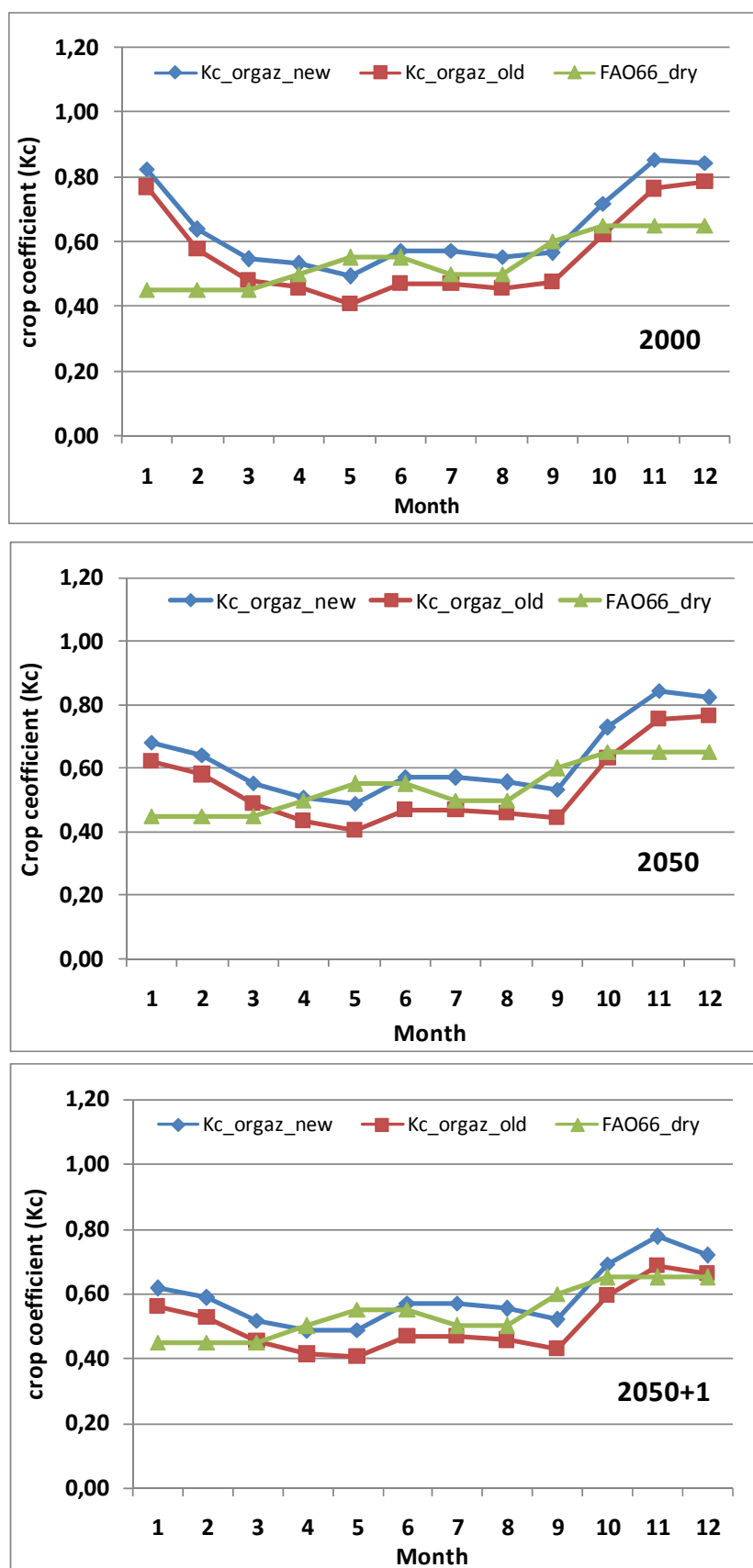


Fig. 27 - Trends of monthly Kc coefficients for olive in Jordan river basin (Jordan) under “present”, “future” and “extreme weather” climate conditions.

3.5.2. Crop evapotranspiration and irrigation requirements

The impact of climate change on maximum and effective crop evapotranspiration as well as on net irrigation requirements, also considering the relative effect of selected adaptation strategies (deficit irrigation strategies), is summarized in the following tables and graphs. In brief, the following observations are reported:

- maximum seasonal crop evapotranspiration is projected to increase for all crop models under “future” (2050) scenario, because of the fixed duration of cycle length and probably as a consequence of the expected increase in daily ET_o , on average of about +5.0% with respect to current conditions (2000) (fig. 28 and tab. 38);
- if “extreme weather” conditions (2050+1) are considered, the projected maximum evapotranspiration variation is slightly higher (on average of about +5.9%), but with some differences between the models (fig. 28 and tab. 38);
- the relative effect of the projected increase and/or decrease of rainfall patterns (during the period March-November), seems to be slightly important for the crop water balance, because of the very low values with respect to crop water needs (tab. 39), with the exception of rainfed conditions (in which rain is the only source of water);
- the higher values of maximum seasonal crop evapotranspiration are observed for the “new” cropping type, under all climate scenarios (fig. 28 and tab. 38);
- ETc_{eff} and NIR are both highly dependent on the irrigation strategy, progressively reducing going from full irrigation to rainfed conditions, under all climate scenarios (fig. 28 and tab. 40-41);
- ETc_{eff} is projected to increase under both 2050 (on average +5.4%) and 2050+1 (+5%) scenarios, for all irrigation strategies with the exception of rainfed conditions (in which an opposite behaviour is projected because of the strong reduction of the rainfall patterns under “extreme weather”);
- as a consequence, NIR is projected to increase for all irrigation strategies under both 2050 (on average +7.8%) and 2050+1 (+12.3%) scenarios.

Tab. 38 – Maximum crop evapotranspiration as estimated by different Kc models for olive in Jordan river basin (Jordan) under “present”, “future” and “extreme weather” climate conditions.

Crop model	ETc_max 2000	ETc_max 2050		ETc_max 2050 +1	
	[mm/season]	[mm/season]	(variation vs 2000)	[mm/season]	(variation vs 2000)
Old_Orgaz_270	842.0	880.5	4.6%	878.5	4.3%
New_Orgaz_270	1000.6	1048.0	4.7%	1050.1	4.9%
FAO66_270	941.2	994.4	5.7%	1019.3	8.3%
average	927.9	974.3	5.0%	982.6	5.9%

Tab. 39 – Effective rainfall pattern during crop cycle of olive in Jordan river basin (Jordan) under “present”, “future” and “extreme weather” climate conditions.

Crop model	Rain_eff 2000	Rain_eff 2050		Rain_eff 2050 +1	
	[mm/season]	[mm/season]	(variation vs 2000)	[mm/season]	(variation vs 2000)
Old_Orgaz_270	57.6	63.5	10.3%	31.5	-45.2%
New_Orgaz_270	57.6	63.5	10.3%	31.5	-45.2%
FAO66_270	57.6	63.5	10.3%	31.5	-45.2%
average	57.6	63.5	10.3%	31.5	-45.2%

Tab. 40 – Effect of irrigation strategies on the effective crop evapotranspiration of olive in Jordan river basin (Jordan) under “present”, “future” and “extreme weather” climate conditions.

Irrigation strategy	ETc_eff 2000	ETc_eff 2050		ETc_eff 2050+1	
	[mm/season]	[mm/season]	(variation vs 2000)	[mm/season]	(variation vs 2000)
full	927.9	974.3	5.0%	982.6	5.9%
mild1	889.8	934.6	5.0%	939.0	5.5%
mild2	796.9	832.6	4.5%	835.7	4.9%
medium	726.7	775.0	6.6%	776.8	6.9%
severe1	642.8	676.3	5.2%	667.7	3.9%
severe2	448.9	476.2	6.1%	463.3	3.2%
rainfed	169.9	174.3	2.6%	145.9	-14.2%

Tab. 41 – Effect of irrigation strategies on the net irrigation requirements of olive in Jordan river basin (Jordan) under “present”, “future” and “extreme weather” climate conditions.

Irrigation strategy	NIR 2000	NIR 2050		NIR 2050 +1	
	[mm/season]	[mm/season]	(variation vs 2000)	[mm/season]	(variation vs 2000)
full	829.4	884.2	6.6%	901.7	8.7%
mild1	743.2	802.6	8.0%	835.6	12.4%
mild2	663.5	707.3	6.6%	721.4	8.7%
medium	565.1	614.9	8.8%	654.8	15.9%
severe1	483.1	521.7	8.0%	543.2	12.4%
severe2	282.5	307.5	8.8%	327.4	15.9%
rainfed	0.0	0.0	0.0%	0.0	0.0%

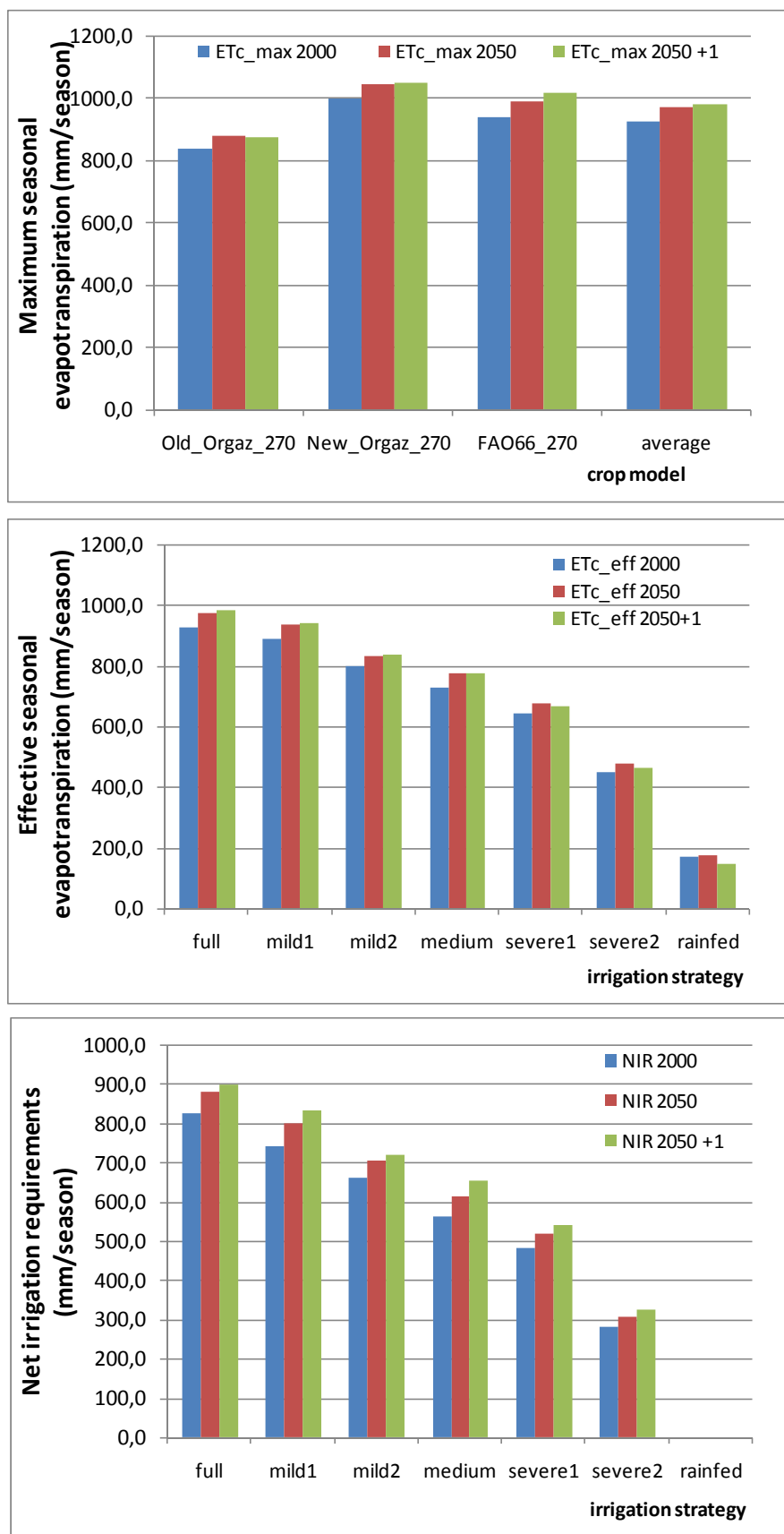


Fig. 28 – Effect of Kc model and irrigation strategies on maximum and effective crop evapotranspiration and net irrigation requirements of olive in Jordan river basin (Jordan) under “present”, “future” and “extreme weather” climate conditions.

3.5.3. Yield response to water

The impact of climate change on potential yield, considering the relative effect of selected adaptation strategies (deficit irrigation strategies), as estimated by the two different yield response models of Rao *et al.* (1988) and Moriana *et al.* (2003) (presented in chapter 2.1.3) are summarized in the following tables and graphs.

According to the results of the first model (Rao *et al.*, 1988) (tab. 42-43 and fig.29):

- yield is projected to increase under both “future” (2050) and “extreme weather” (2050+1) scenarios with respect to current conditions (2000), on average respectively from 13.9 to 14.6 (about +5%) and to 14.7 t ha⁻¹ (+5.9%), depending on irrigation strategies and Kc model considered, as a consequence of the expected increase of ETC;
- a clear linear reduction in potential yield under increasing water stress conditions is observed (fig.29);
- under “severe” water stress (thus only supported by supplemental irrigations) values of 4-7 t ha⁻¹ are still predicted;
- in the case of rainfed conditions, very low yield (around 1 t ha⁻¹) is predicted.

According to the results of the alternative model (Moriana *et al.*, 2003) (tab. 44-45 and fig.30):

- yield is projected to remain relatively stable or slightly decrease under both “future” (2050) and “extreme weather” (2050+1) scenarios with respect to current conditions (2000), on average from 11.5 to 11.3 (about -1.4%), depending on irrigation strategies and Kc model considered;
- as a consequence of the specific shape of the yield response function curve, a relative stability of potential yield is predicted going from full irrigated to medium stressed conditions, and then reducing under severe stress (only supported by supplemental irrigations) where values of 4-9 t ha⁻¹ are still predicted;
- in the case of rainfed conditions, no yield is predicted.

Tab. 42 – Effect of irrigation strategies on the potential yield of olive in Jordan river basin (Jordan) under “present”, “future” and “extreme weather” climate conditions.

Irrigation strategy	Yield 2000 (*)	Yield 2050 (*)		Yield 2050 +1	
	(t/ha)	(t/ha)	(variation vs 2000)	(t/ha)	(variation vs 2000)
full	13.9	14.6	5.0%	14.7	5.9%
mild1	13.0	13.7	5.2%	13.7	5.3%
mild2	10.2	10.6	4.2%	10.6	3.9%
medium	9.4	10.1	7.6%	10.1	7.1%
severe1	7.1	7.5	5.6%	7.3	3.1%
severe2	4.1	4.4	6.4%	4.2	3.2%
rainfed	1.0	1.0	8.7%	0.9	-3.6%
(*) assuming wp (2000) = 1.5 (kg/m3)					

Tab. 43 – Effect of different Kc models on the potential yield of olive in Jordan river basin (Jordan) under “present” and “future” climate conditions.

Crop model	Yield 2000 (*)	Yield 2050 (*)		Yield 2050 +1 (*)	
	(t/ha)	(t/ha)	(variation vs 2000)	(t/ha)	(variation vs 2000)
Old_Orgaz_270	12.6	13.2	4.6%	13.2	4.3%
New_Orgaz_270	15.0	15.7	4.7%	15.8	4.9%
FAO66_270	14.1	14.9	5.7%	15.3	8.3%
average	13.9	14.6	5.0%	14.7	5.9%
(*) assuming wp (2000) = 1.5 (kg/m3)					

Tab. 44 – Effect of irrigation strategies on the potential yield of olive in Jordan river basin (Jordan) (as modelled according to Moriana *et al.* 2003) under “present”, “future” and “extreme weather” climate conditions.

Irrigation strategy	Yield 2000 (**)	Yield 2050 (**)		Yield 2050 +1 (**)	
	(t/ha)	(t/ha)	(variation vs 2000)	(t/ha)	(variation vs 2000)
full	11.5	11.3	-1.4%	11.3	-1.8%
mild1	11.5	11.5	-0.3%	11.5	-0.4%
mild2	11.1	11.4	1.9%	11.4	2.0%
medium	10.5	11.0	4.8%	11.0	5.0%
severe1	9.2	9.8	6.1%	9.6	4.6%
severe2	4.4	5.2	19.0%	4.8	10.1%
rainfed	0.0	0.0		0.0	
(**) according to the model proposed by Moriana <i>et al.</i> (2003)					

Tab. 45 – Effect of different Kc models on the potential yield of olive in Jordan river basin (Jordan) (as modelled according to Moriana *et al.* 2003) under “present” and “future” climate conditions.

Crop model	Yield 2000 (**)	Yield 2050 (**)		Yield 2050 +1 (**)	
	(t/ha)	(t/ha)	(variation vs 2000)	(t/ha)	(variation vs 2000)
Old_Orgaz_270	11.4	11.5	0.9%	11.5	0.9%
New_Orgaz_270	11.2	10.7	-3.7%	10.7	-3.9%
FAO66_270	11.5	11.2	-2.2%	11.0	-3.8%
average	11.5	11.3	-1.4%	11.3	-1.8%
(**) according to the model proposed by Moriana <i>et al.</i> (2003)					

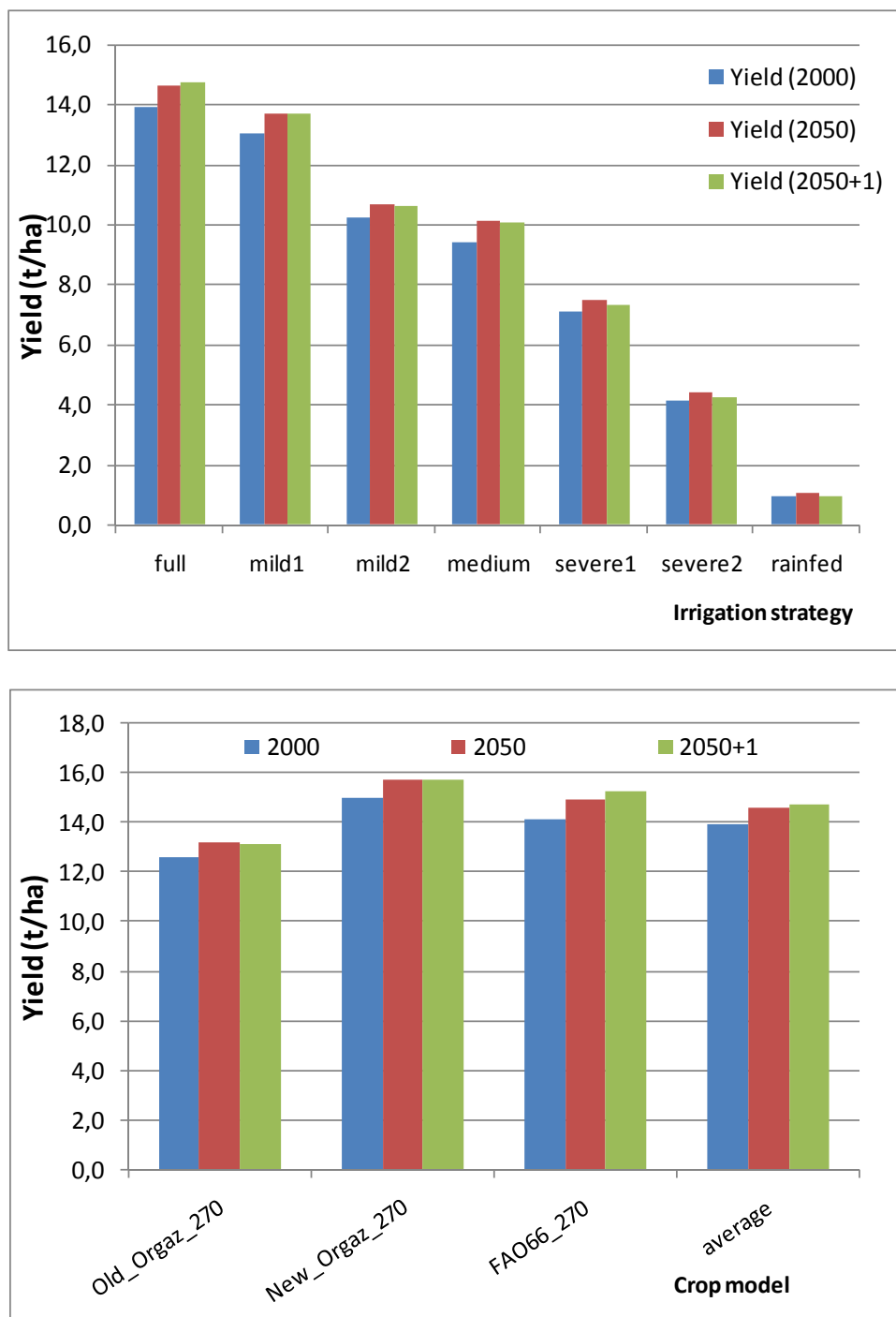


Fig. 29 – Effect of irrigation strategies and Kc model on potential yield of olive in Jordan river basin (Jordan) under “present” and “future” climate conditions.

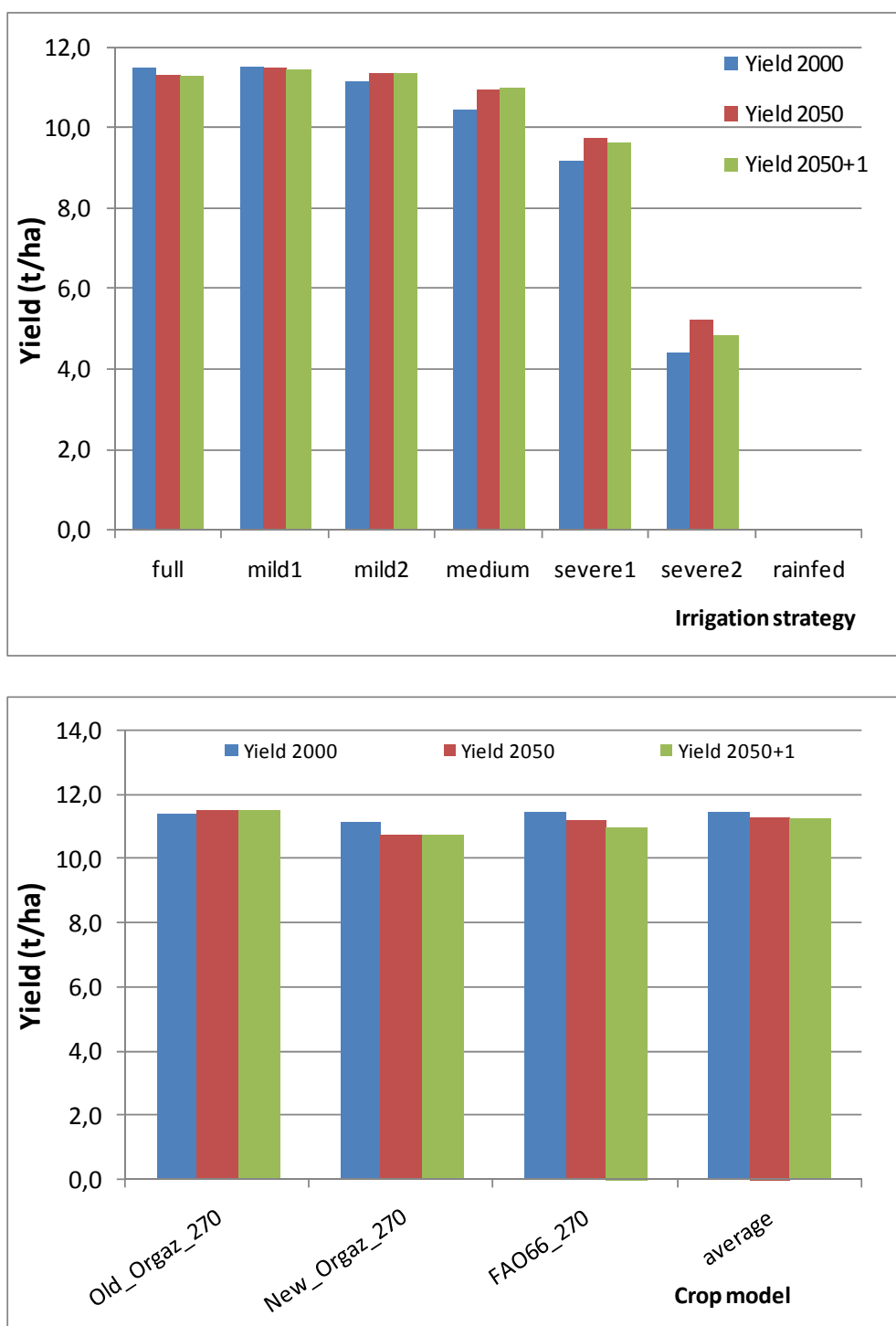


Fig. 30 – Effect of irrigation strategies and Kc model on potential yield of olive in Jordan river basin (Jordan) (as modelled according to Moriana *et al.* 2003) under “present” and “future” climate conditions.

4. Case study: Merguellil catchment (Tunisia)

4.1. Climate projections and reference evapotranspiration

With respect to climate projections, as summarized in the following tables and graphs, the following observation are predicted:

- an important reduction of the annual rainfall pattern (-22.3 mm/year), with alternative variations (increasing or decreasing) at monthly scale;
- a relevant increase (+118.6 mm) of annual reference evapotranspiration, especially during spring-summer months (with values up to +20.3 mm/month in May), and with a “peak” of daily evapotranspiration in July (8.9 mm/day);

Tab. 46 – Monthly and annual average values of predicted rainfall and evapotranspiration under present and future climate conditions in Merguellil catchment (Tunisia).

Month	Rain			ETo		
	2000	2050	var. (mm)	2000	2050	var. (mm)
1	33.8	33.2	-0.62	67.1	71.8	4.73
2	28.4	14.3	-14.17	79.7	82.6	2.90
3	35.4	45.8	10.40	121.4	126.8	5.40
4	7.0	5.2	-1.72	155.1	167.3	12.21
5	22.0	15.2	-6.86	205.7	226.0	20.32
6	9.2	2.8	-6.38	243.0	260.2	17.20
7	4.4	13.9	9.50	263.0	277.1	14.18
8	24.9	18.7	-6.23	231.1	241.8	10.69
9	29.0	21.4	-7.56	159.5	172.5	12.92
10	14.4	33.5	19.08	110.9	119.9	8.98
11	35.2	25.4	-9.78	75.9	77.8	1.90
12	20.6	12.6	-7.95	61.1	68.3	7.14
Total	264.2	242.0	-22.28	1773.4	1892.0	118.57

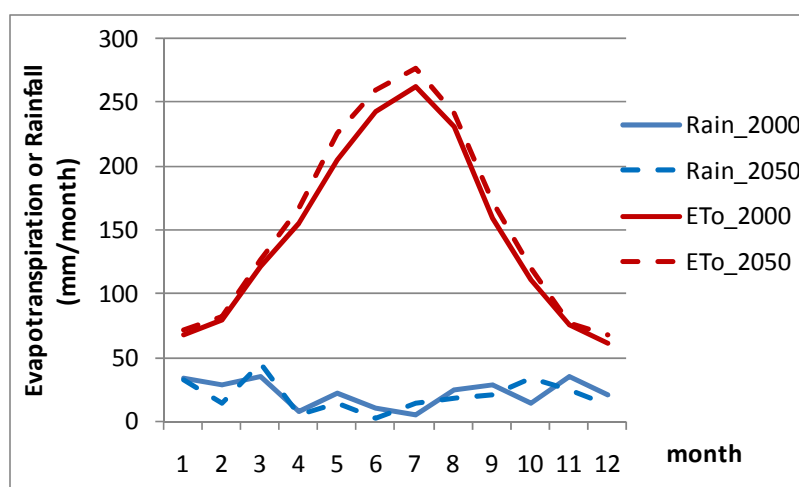


Fig. 31 – Monthly trends of predicted rainfall and evapotranspiration under present and future climate conditions in Merguellil catchment (Tunisia).

- an important increase in annual average maximum, minimum and average air temperatures, up to +1.7°C;
- a wide distributed increase in monthly average maximum, minimum and average air temperature, with values ranging from +1 to 2.3°C/month, with the higher increase predicted during summer months;
- an increase in the “peak” air temperature during the hotter month of July, with average maximum value projected to reach 37.4°C.

Tab.47 – Monthly and annual average values and relative variations of predicted maximum, minimum and average air temperature under present and future climate conditions in Merguellil catchment (Tunisia).

Month	Tmax			Tmin			Tmean		
	2000	2050	var. (°C)	2000	2050	var. (°C)	2000	2050	var. (°C)
1	13.7	14.9	1.2	5.1	6.0	0.9	9.4	10.5	1.1
2	15.3	16.6	1.3	5.5	6.5	1.0	10.4	11.5	1.2
3	18.5	19.4	1.0	6.9	7.8	0.9	12.7	13.6	0.9
4	22.1	23.6	1.5	9.0	10.2	1.2	15.5	16.9	1.4
5	26.9	29.1	2.2	12.3	14.0	1.7	19.6	21.5	2.0
6	32.3	34.5	2.1	16.4	18.1	1.7	24.4	26.3	1.9
7	35.3	37.4	2.1	19.2	21.1	1.9	27.3	29.3	2.0
8	34.1	36.1	2.0	19.0	21.0	2.0	26.5	28.6	2.0
9	29.0	31.4	2.3	16.3	18.4	2.0	22.7	24.9	2.2
10	23.4	25.1	1.8	12.8	14.4	1.6	18.1	19.8	1.7
11	17.9	19.0	1.1	9.0	10.2	1.1	13.5	14.6	1.1
12	14.1	15.8	1.7	6.0	7.3	1.3	10.1	11.6	1.5
Average	23.5	25.2	1.7	11.5	12.9	1.4	17.5	19.1	1.6

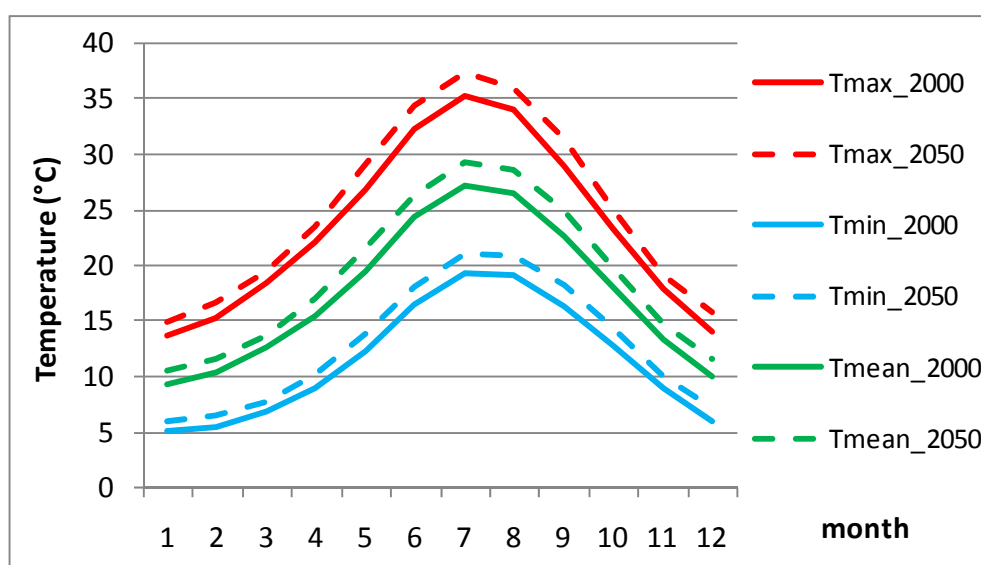


Fig. 32 – Monthly trends of predicted maximum, minimum and mean air temperatures under present and future climate conditions in Merguellil catchment (Tunisia).

4.2. Wheat

4.2.1. Cycle length and crop coefficient curves

The effect of temperature increase (and relative GDD accumulation) on current and projected crop cycle length and corresponding crop coefficient curves is represented in the following graphs, and the following observations have to be highlighted:

- if varietal adaptation is not considered, an important reduction of the total growing cycle is predicted for all planting dates, because of the faster accumulation of the required GGD sum under “future” climate conditions (2050) (fig. 33-34);
- on the contrary, if a late maturing variety will be used, the total crop cycle length (2050 late_var) is projected to remain relatively the same as for the current variety under “present” climate conditions (2000) (fig.34);
- with respect to the four crop coefficient stages, a relative reduction is predicted in proportion to the corresponding increase in the cumulative GDD (lower during winter, higher during spring-summer months), both in the case of early (November) and late (February) sowing dates (fig. 33).

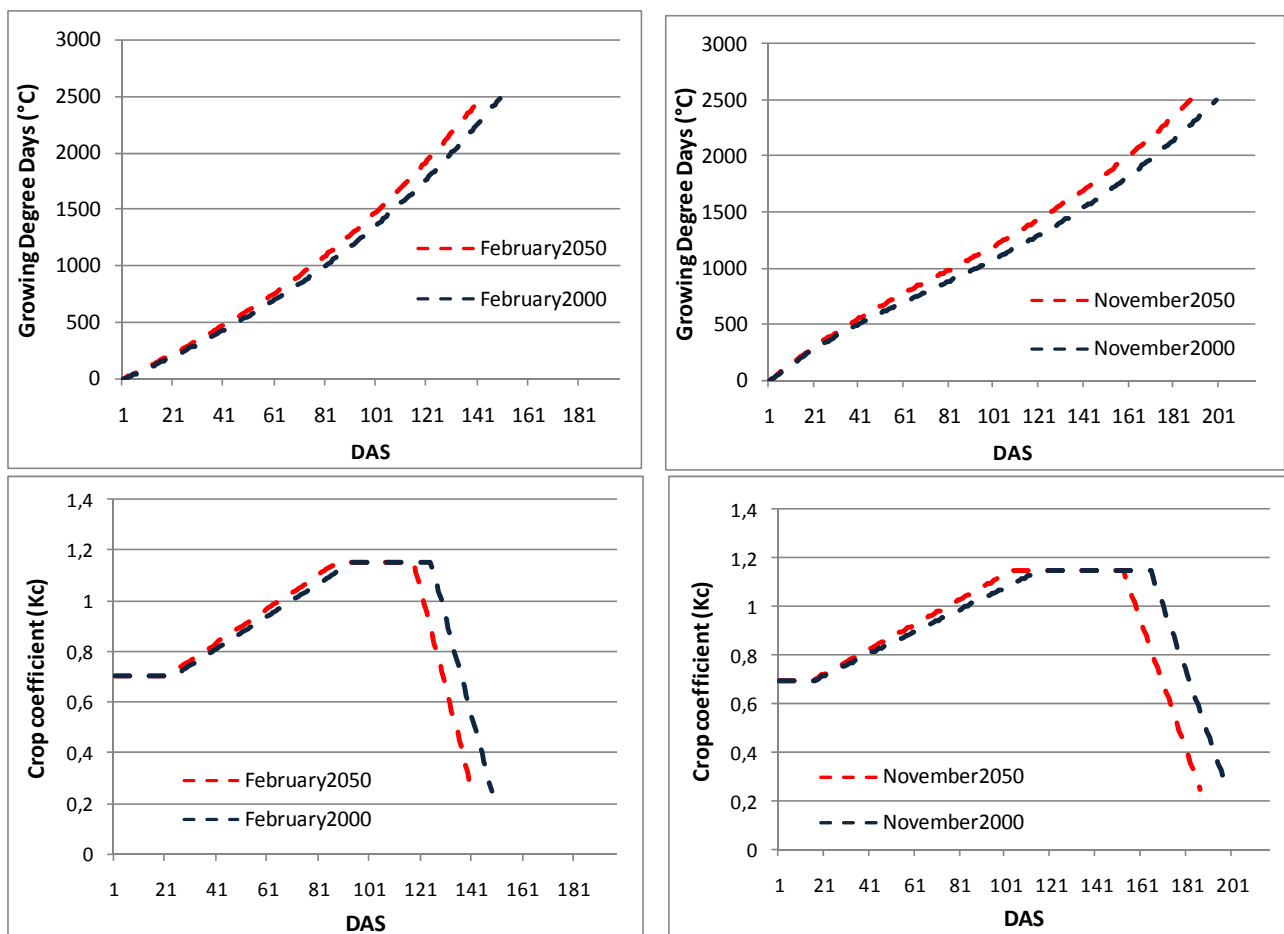


Fig. 33 – Predicted cumulative GDD and corresponding Kc curves for wheat in Merguellil catchment (Tunisia) as affected by different planting dates and climate scenarios.

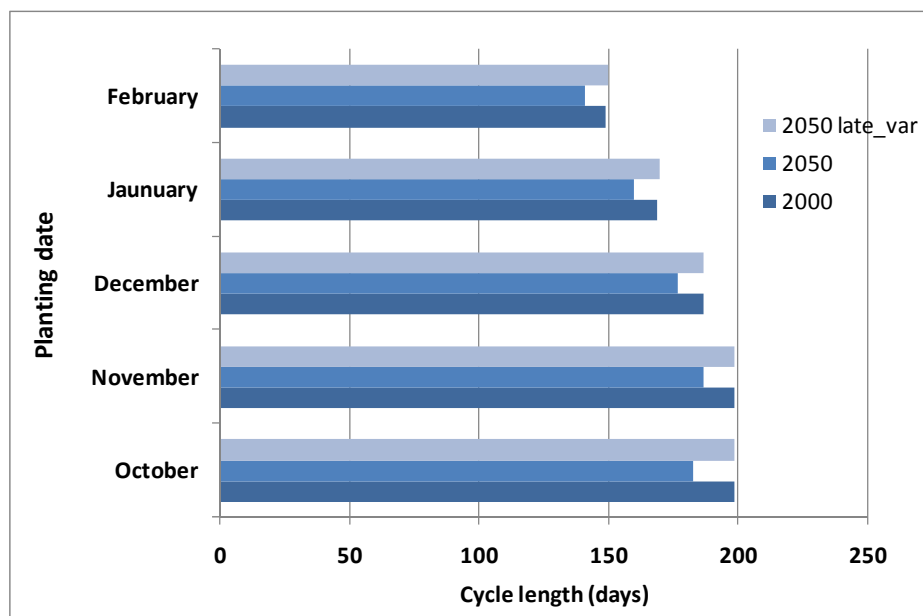


Fig. 34 – Length of total growing cycle of wheat in Merguellil catchment (Tunisia) as affected by planting date, variety selection and climate variations.

4.2.2. Crop evapotranspiration and irrigation requirements

The impact of climate change on maximum and effective crop evapotranspiration as well as on net irrigation requirements, also considering the relative effect of selected adaptation strategies (planting dates, variety selection and deficit irrigation strategies), is summarized in the following tables and graphs. In brief, the following observations are reported:

- maximum seasonal crop evapotranspiration is projected to reduce for the current variety under “future” (2050) scenario as a consequence of the expected shortening of the crop growing cycle, on average of about -4.6% with respect to current conditions (2000) (fig. 36 and tab. 48);
- on the contrary, if a late maturing variety (2050 late_var) is selected, maximum evapotranspiration is projected to increase (+7.6%) for all the planting dates (fig. 36 and tab. 48);
- the relative effect of the projected variation of rainfall patterns (-13.6%) seems to be slightly important the crop water balance, due to their very low values in absolute terms (tab.49);
- maximum seasonal crop evapotranspiration is observed always to increase (in absolute terms) for late (February) planting date with respect to earlier (October) ones, because of the shifting of most of the cycle towards the spring-summer season (fig. 36 and tab. 48);
- effective seasonal crop evapotranspiration and net irrigation requirements are both highly dependent on the irrigation strategy, progressively reducing going from full irrigation to rainfed conditions (fig. 36 and tab.50-51);
- as for ET_{c_max} , also the ET_{c_eff} and NIR are projected to decrease in 2050 if the current variety is used, or to increase if a late maturing variety is selected, especially under full irrigated to mild stress conditions (fig. 36 and tab.50-51);

Tab. 48 – Effect of planting date and variety selection on the maximum crop evapotranspiration of wheat in Merguellil catchment (Tunisia) under “present” and “future” climate conditions.

Planting date	ETc_max 2000	ETc_max 2050		ETc_max 2050 late_var	
	[mm/season]	[mm/season]	(variation vs 2000)	[mm/season]	(variation vs 2000)
october	521.8	477.5	-8.5%	551.8	5.8%
november	607.5	566.3	-6.8%	647.0	6.5%
december	666.5	639.1	-4.1%	717.4	7.6%
january	685.5	663.3	-3.2%	742.8	8.4%
february	727.5	716.7	-1.5%	794.0	9.1%
average	641.8	612.6	-4.6%	690.6	7.6%

Tab. 49 – Effect of planting date and variety selection on the effective rainfall pattern during crop cycle of wheat in Merguellil catchment (Tunisia) under “present” and “future” climate conditions.

Planting date	Rain_eff 2000	Rain_eff 2050		Rain_eff 2050 late_var	
	[mm/season]	[mm/season]	(variation vs 2000)	[mm/season]	(variation vs 2000)
october	139.9	131.9	-5.7%	136.1	-2.7%
november	137.7	117.1	-14.9%	119.2	-13.4%
december	117.8	101.1	-14.2%	101.1	-14.2%
january	90.3	75.8	-16.1%	75.8	-16.1%
february	81.6	64.4	-21.1%	66.6	-18.4%
average	113.4	98.0	-13.6%	99.7	-12.1%

Tab.50 – Effect of irrigation strategies and variety selection on the effective evapotranspiration of wheat in Merguellil catchment (Tunisia) under “present” and “future” climate.

Irrigation strategy	ETc_eff 2000	ETc_eff 2050		ETc_eff 2050 late_var	
	[mm/season]	[mm/season]	(variation vs 2000)	[mm/season]	(variation vs 2000)
full	641.7	612.4	-4.6%	690.4	7.6%
mild1	620.1	577.4	-6.9%	648.3	4.6%
mild2	577.2	550.0	-4.7%	613.6	6.3%
medium	542.6	472.4	-12.9%	528.9	-2.5%
severe1	487.1	453.8	-6.8%	501.8	3.0%
severe2	386.2	342.2	-11.4%	373.1	-3.4%
rainfed	227.2	210.3	-7.4%	215.1	-5.3%

Tab. 51 – Effect of irrigation strategies and variety selection on the net irrigation requirements of wheat in Merguellil catchment (Tunisia) under “present” and “future” climate conditions.

Irrigation strategy	NIR 2000	NIR 2050		NIR 2050 late_var	
	[mm/season]	[mm/season]	(variation vs 2000)	[mm/season]	(variation vs 2000)
full	486.5	469.3	-3.5%	550.7	13.2%
mild1	462.7	412.5	-10.8%	490.3	6.0%
mild2	389.2	375.4	-3.5%	440.5	13.2%
medium	341.4	289.0	-15.3%	349.5	2.4%
severe1	300.8	268.1	-10.8%	318.7	6.0%
severe2	170.7	144.5	-15.3%	174.8	2.4%
rainfed	0.0	0.0	0.0%	0.0	0.0%

- by plotting together the values of seasonal ETc_{eff} and NIR (obtained under different irrigation strategies and variety) for different climate scenarios, there is a clear prediction of their reduction (respectively of about -7.2% and -7.3%, on average) while, by considering a late maturing variety, an increase of both (respectively of about +3.3% and +9%, on average) (fig. 35);
- the cumulative curves of ETc_{max} in 2050 show always (also under different planting dates) their shifting towards higher values (with respect to 2000), thus representing the relative increase in the daily crop water requirements, although with a decrease in the cumulative final value (depending on the anticipated ending of the cycle) (fig. 37).

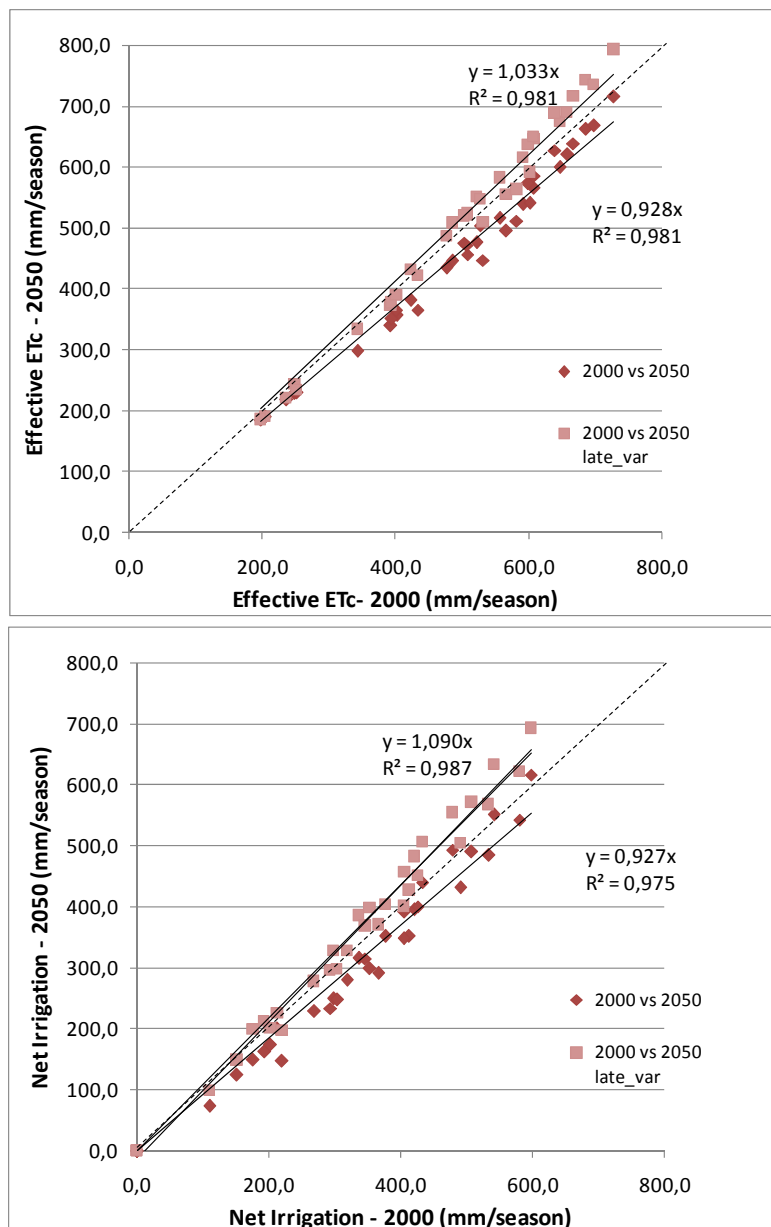


Fig. 35 – Scatter-plot of seasonal crop evapotranspiration and net irrigation requirements of as affected by different variety selection for wheat in Merguellil catchment (Tunisia) under “present” and “future” climate conditions.

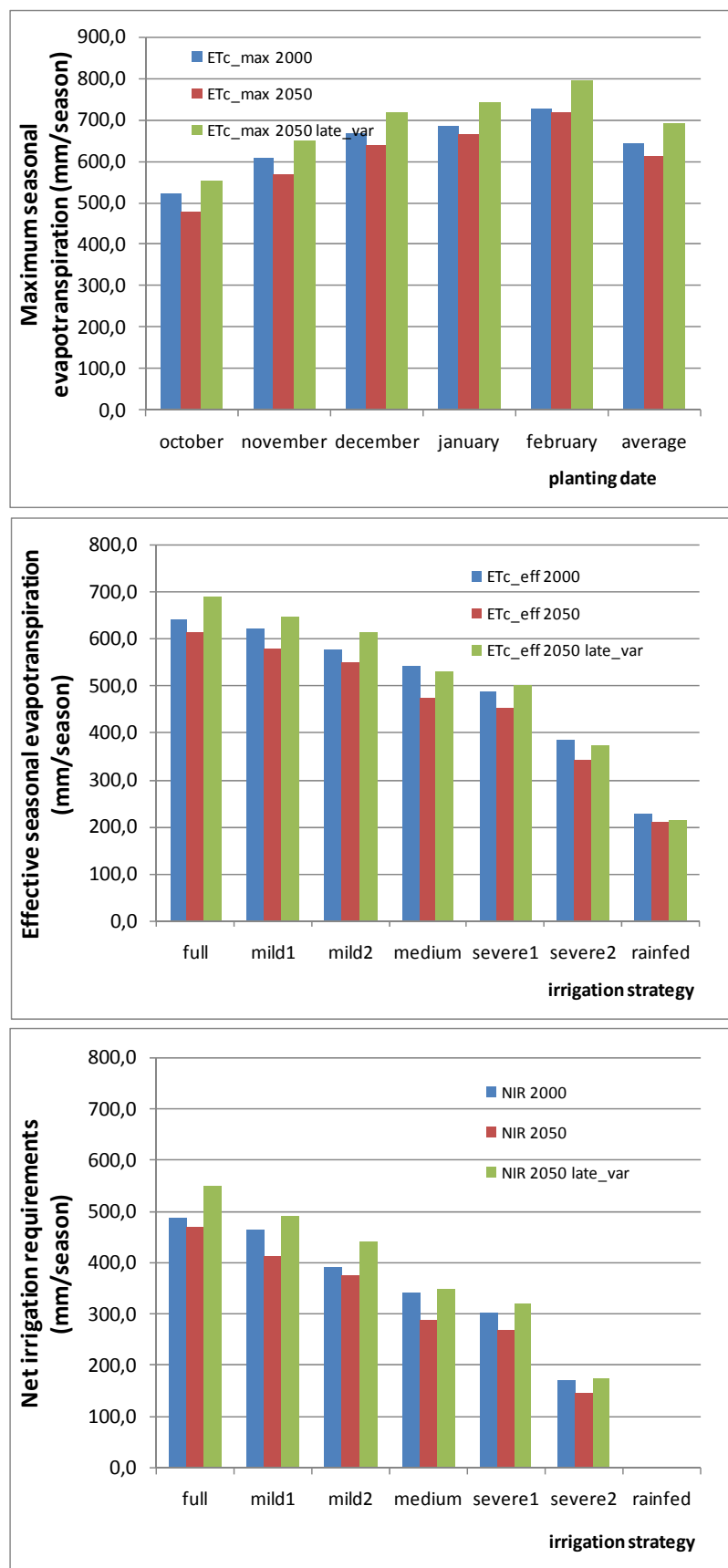


Fig. 36 – Effect of planting date, irrigation strategies and variety selection on maximum and effective crop evapotranspiration and net irrigation requirements of wheat in Merguellil catchment (Tunisia) under “present” and “future” climate conditions.

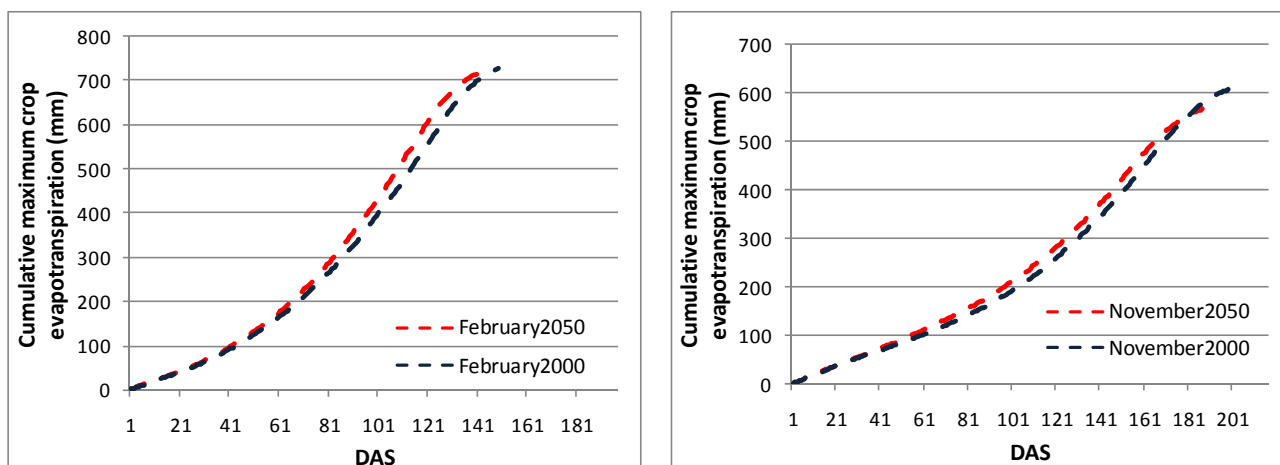


Fig. 37 – Cumulative curves of maximum crop evapotranspiration as affected by different planting date for wheat in Merguellil catchment (Tunisia) under “present” and “future” climate conditions.

4.2.3. Crop evapotranspiration under extreme weather conditions

If a simulated future “extreme weather” climate condition (2050+1) is considered (created by adding +1°C to daily temperature of 2050 climate scenario), the following observations on crop cycle length are reported (fig.38):

- with current variety, a further important reduction of the total growing cycle is predicted for quite all planting dates with respect to 2000 and 2050 scenario, because of the faster accumulation of the required GDD sum;
- if a late maturing variety is considered, the total crop cycle length (2050+1 late_var) is partly recovered with respect to present (2000) scenario only in the case of late planting dates (January, February), while it is significantly shortened in all other cases with respect to 2050 late_var and 2000 scenarios.

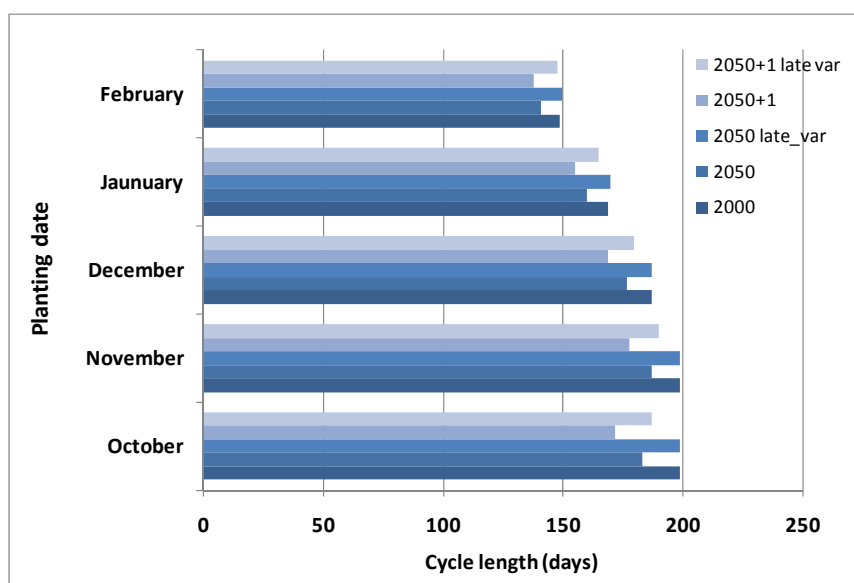


Fig. 38 – Length of total growing cycle of wheat in Merguellil catchment (Tunisia) as affected by planting date and variety selection under “present (2000)”, “future (2050)” and “future extreme weather (2050+1)” climate conditions.

The impact of future “extreme weather” conditions (2050+1) on maximum and effective crop evapotranspiration as well as on net irrigation requirements, also considering the relative effect of selected adaptation strategies (planting dates, variety selection and deficit irrigation strategies), is summarized in the following tables and graphs. In brief, the following observations are reported:

- *ETc_max* is projected to reduce for the current variety under future “extreme weather” (2050+1) scenario as a consequence of the expected further shortening of the crop growing cycle, on average of about –6.8% with respect to present conditions (2000); on the contrary, if a late maturing variety (2050+1 late_var) is selected, *ETc_max* is projected to increase (+5.1% on average) (tab. 52);
- *ETc_max* is observed always to increase (in absolute terms) for late (February) planting date with respect to earlier (October) ones, because of the shifting of most of the cycle towards the hotter spring-summer season (fig. 39 and tab.52);
- the relative effect of the projected variation of rainfall patterns (close to -40%) seems to be relevant for the crop water balance, because of the reduction of about 50 mm during the cropping season (tab. 53);
- *ETc_eff* is projected to decrease under 2050+1 scenario if the current variety is used; if a late maturing variety is selected (tab. 54), it is projected to decrease (under rainfed and severe conditions) or to increase (under better irrigated conditions), always with respect to 2000 baseline scenario;
- on the other side, *NIR* is projected to remain stable or slightly increase under 2050+1 scenario if the current variety is used, or again to increase significantly if a late maturing variety is selected (tab. 55), always with respect to 2000 baseline scenario;
- *ETc_eff* and *NIR* are both highly dependent on the irrigation strategy, progressively reducing going from full irrigation to rainfed conditions, under all climate scenarios (fig.39);
- by plotting together the values of seasonal *ETc_eff* and *NIR* for 2000 versus 2050+1 climate scenarios, there is a clear prediction of *ETc_eff* reduction and *NIR* slight increase with current variety (respectively of about -8.5% and +1.6%, on average), or of their increase if a late maturing variety is considered (respectively of about +2.1% and +16.8%, on average) (fig. 40).

Tab. 52 – Effect of planting date and variety selection on the maximum crop evapotranspiration of wheat in Merguellil catchment (Tunisia) under “present”, “future” and “future extreme weather” climate conditions.

Planting date	ETc_max 2000	ETc_max 2050		ETc_max 2050 late_var		ETc_max 2050+1		ETc_max 2050+1 late_var	
	(mm)	(mm)	var.%(2000)	(mm)	var.%(2000)	(mm)	var.%(2000)	(mm)	var.%(2000)
october	521.8	477.5	-8.5%	551.8	5.8%	464.9	-10.9%	529.0	1.4%
november	607.5	566.3	-6.8%	647.0	6.5%	543.5	-10.5%	620.4	2.1%
december	666.5	639.1	-4.1%	717.4	7.6%	615.8	-7.6%	695.0	4.3%
january	685.5	663.3	-3.2%	742.8	8.4%	649.9	-5.2%	728.4	6.2%
february	727.5	716.7	-1.5%	794.0	9.1%	716.2	-1.5%	800.9	10.1%
average	641.8	612.6	-4.6%	690.6	7.6%	598.1	-6.8%	674.7	5.1%

Tab. 53 – Effect of planting date and variety selection on the effective rainfall pattern during crop cycle of wheat in Merguellil catchment (Tunisia) under “present”, “future” and “future extreme weather” climate conditions.

Planting date	Rain_eff 2000	Rain_eff 2050		Rain_eff 2050 late_var		Rain_eff 2050+1		Rain_eff 2050+1 late_var	
	(mm)	[mm/season]	var.%(2000)	(mm)	var.%(2000)	(mm)	var.%(2000)	(mm)	var.%(2000)
october	139.9	131.9	-5.7%	136.1	-2.7%	86.4	-38.2%	92.3	-34.0%
november	137.7	117.1	-14.9%	119.2	-13.4%	76.5	-44.5%	82.0	-40.5%
december	117.8	101.1	-14.2%	101.1	-14.2%	69.3	-41.2%	70.7	-39.9%
january	90.3	75.8	-16.1%	75.8	-16.1%	53.0	-41.3%	53.0	-41.3%
february	81.6	64.4	-21.1%	66.6	-18.4%	45.1	-44.8%	46.6	-42.8%
average	113.4	98.0	-13.6%	99.7	-12.1%	66.1	-41.8%	68.9	-39.2%

Tab. 54 – Effect of irrigation strategies and variety selection on the effective crop evapotranspiration of wheat in Merguellil catchment (Tunisia) under “present”, “future” and “future extreme weather” climate conditions.

Irrigation strategy	ETc_eff 2000	ETc_eff 2050		ETc_eff 2050 late_var		ETc_eff 2050+1		ETc_eff 2050+1 late_var	
	(mm)	(mm)	var.% (2000)	(mm)	var.% (2000)	(mm)	var.% (2000)	(mm)	var.% (2000)
full	641.7	612.4	-4.6%	690.4	7.6%	598.0	-6.8%	674.6	5.1%
mild1	620.1	577.4	-6.9%	648.3	4.6%	576.1	-7.1%	647.0	4.3%
mild2	577.2	550.0	-4.7%	613.6	6.3%	531.9	-7.9%	593.5	2.8%
medium	542.6	472.4	-12.9%	528.9	-2.5%	489.4	-9.8%	550.0	1.4%
severe1	487.1	453.8	-6.8%	501.8	3.0%	442.0	-9.3%	490.0	0.6%
severe2	386.2	342.2	-11.4%	373.1	-3.4%	335.7	-13.1%	367.9	-4.7%
rainfed	227.2	210.3	-7.4%	215.1	-5.3%	179.1	-21.2%	182.8	-19.5%

Tab. 55 – Effect of irrigation strategies and variety selection on the net irrigation requirements of wheat in Merguellil catchment (Tunisia) under “present”, “future” and “future extreme weather” climate conditions.

Irrigation strategy	NIR 2000	NIR 2050		NIR 2050 late_var		NIR 2050+1		NIR 2050+1 late_var	
	(mm)	(mm)	var.% (2000)	(mm)	var.% (2000)	(mm)	var.% (2000)	(mm)	var.% (2000)
full	486.5	469.3	-3.5%	550.7	13.2%	499.1	2.6%	580.0	19.2%
mild1	462.7	412.5	-10.8%	490.3	6.0%	456.6	-1.3%	522.2	12.9%
mild2	389.2	375.4	-3.5%	440.5	13.2%	399.3	2.6%	464.0	19.2%
medium	341.4	289.0	-15.3%	349.5	2.4%	348.3	2.0%	406.9	19.2%
severe1	300.8	268.1	-10.8%	318.7	6.0%	296.8	-1.3%	339.4	12.9%
severe2	170.7	144.5	-15.3%	174.8	2.4%	174.1	2.0%	203.5	19.2%
rainfed	0.0	0.0		0.0		0.0		0.0	

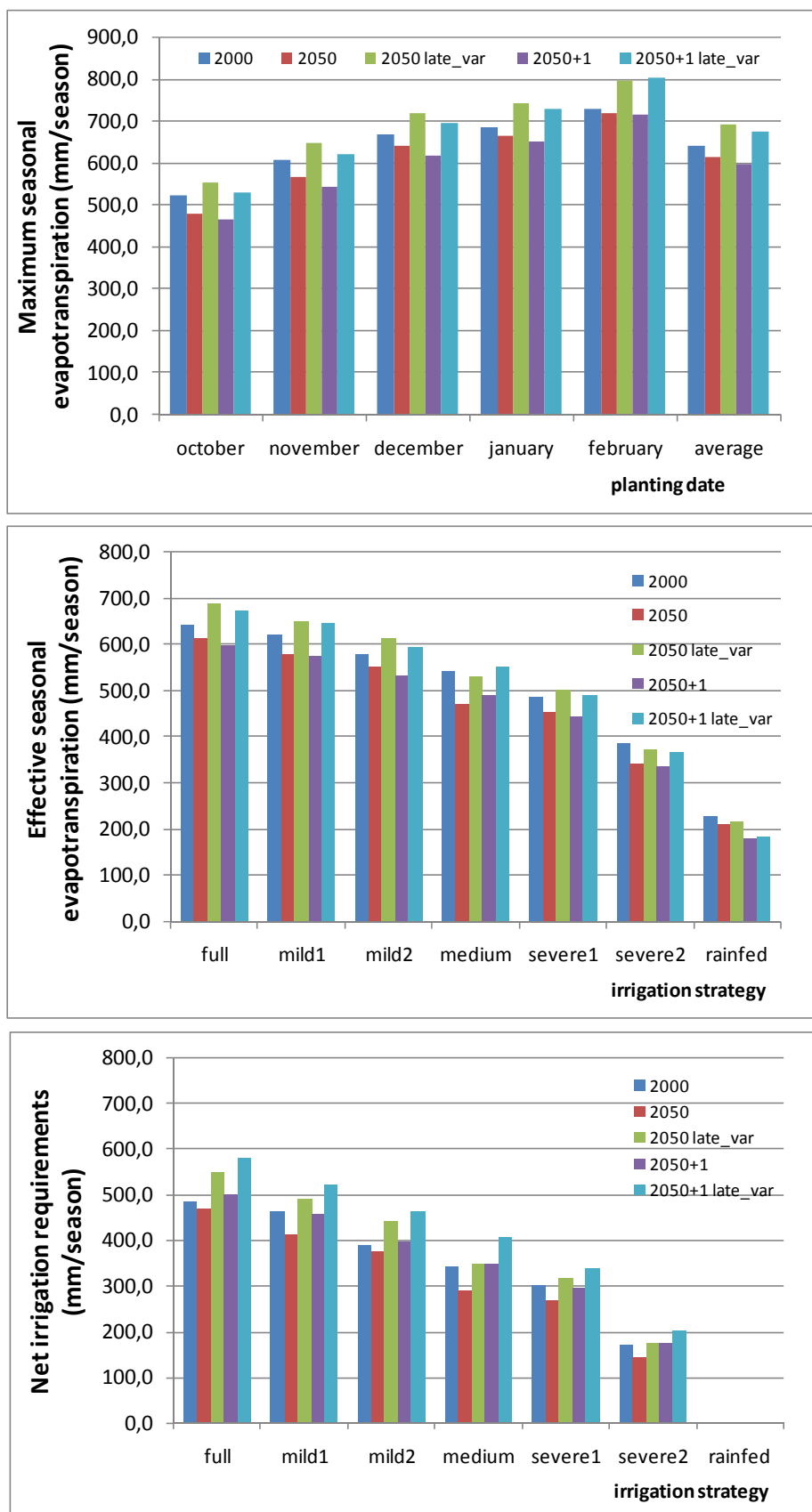


Fig.39 – Effect of planting date, irrigation strategies and variety selection on maximum and effective crop evapotranspiration and net irrigation requirements of wheat in Merguellil catchment (Tunisia) under “present” and “future” and “extreme weather (2050+1)” climate conditions.

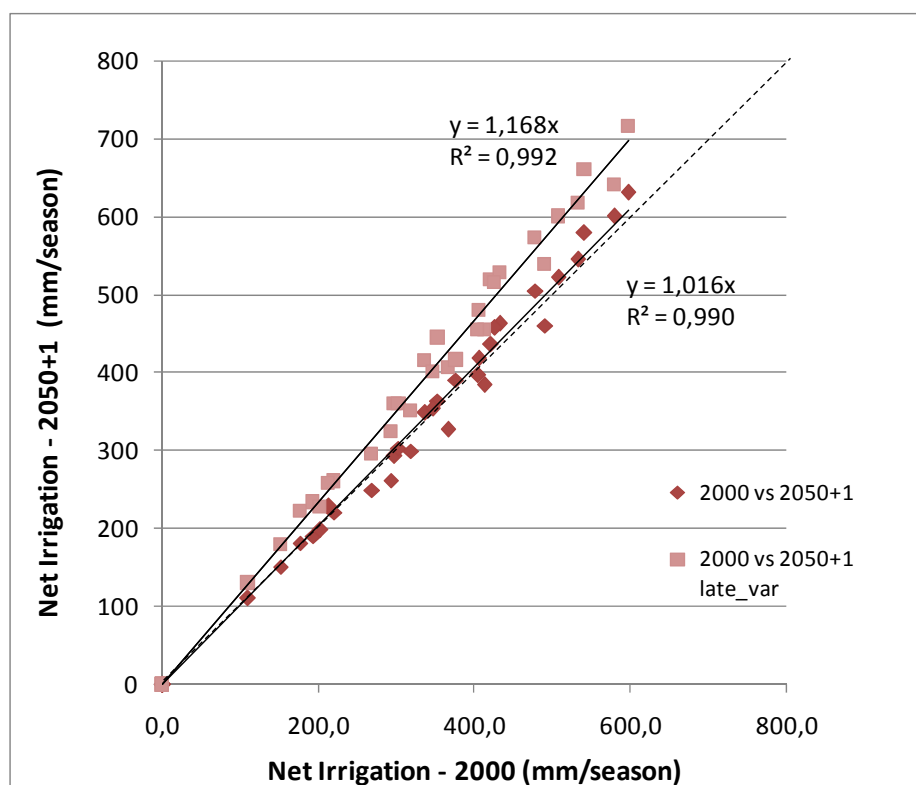
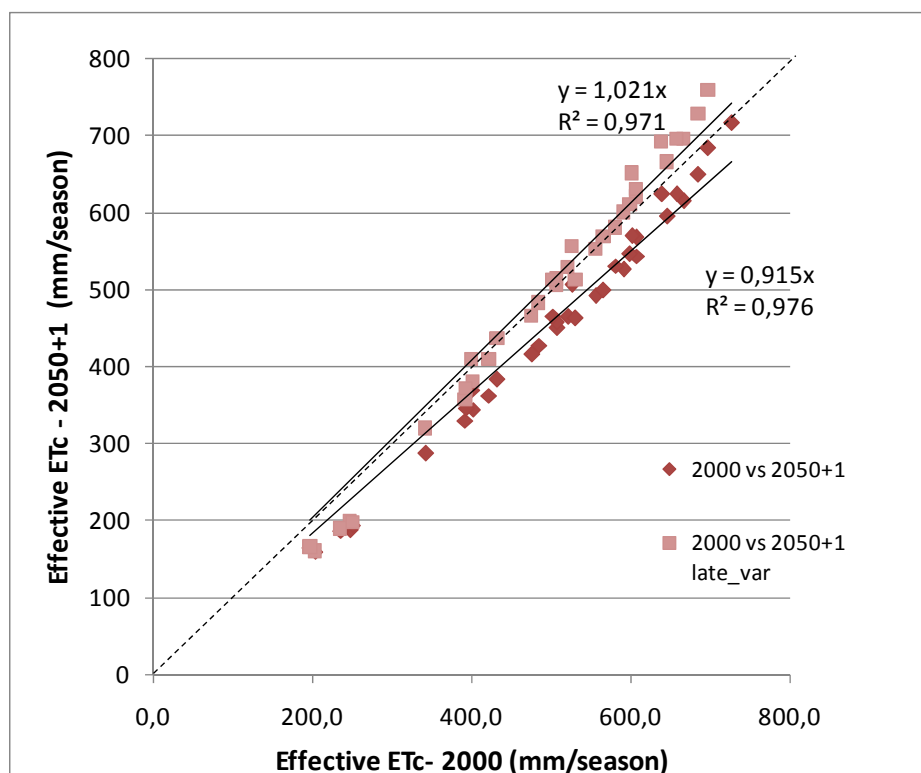


Fig. 40 – Scatter-plot of seasonal crop evapotranspiration and net irrigation requirements of as affected by different variety selection for wheat in Merguellil catchment (Tunisia) under “present (2000)” and “future extreme weather (2050+1)” climate conditions.

4.2.4. Yield response to water

The impact of “future” climate projections (2050) and “extreme weather” (2050+1) on potential yield, also considering the relative effect of selected adaptation strategies (planting dates, variety selection and deficit irrigation strategies), is summarized in the following tables and graphs. In brief, the following observations are reported:

- potential yield is projected to reduce under “future” scenario (2050) with respect to current conditions (2000), on average from 6.4 to 6.1 t ha⁻¹ (about -4.6%), depending on irrigation strategies (tab. 56 and fig.41) and planting dates (tab. 57 and fig.41) as a consequence of the expected shortening of the crop growing cycle;
- on the contrary, if the expected fertilizing effect due to an increase in atmospheric CO₂ concentration will occur, yield is projected to increase in quite all conditions (2050 wp_adj), up to an average of 7.4 t ha⁻¹ (+14.5%), and thus to overcome the effect of the shortening of the crop cycle (fig. 41 and tab.56-57);
- on the other side, if a late maturing variety (2050 late_var) is selected, yield is projected to increase up to an average of 6.9 t ha⁻¹ (+7.6%), especially under fully irrigation (fig. 41 and tab. 56-57);
- if “extreme weather” conditions (2050+1) are considered, the average expected yield reduction (down to 6.0 t ha⁻¹, -6.8%) is greater than in 2050 scenario, but also in this case it could be completely recovered because of the CO₂ fertilizing effect or the late-variety selection, respectively to 7.2 t ha⁻¹ (+11.8%) and 6.7 t ha⁻¹ (+5.1%);
- with respect to irrigation strategies, there is a clear reduction in potential yield under increasing water stress conditions (fig.41), but still under “severe” water stress (thus only supported by supplemental irrigations) values up to 3-4 t ha⁻¹ are expected, while under rainfed conditions, an average yield of 1.5-2 t ha⁻¹ is still predicted in all climate conditions;
- yield is observed always to increase (in absolute terms) for late (February) planting date with respect to earlier (October) ones (fig.41), but a corresponding increase in crop water requirements is clearly projected (as it has been highlighted in the previous paragraph).

Tab. 56 – Effect of irrigation strategies, variety selection and atmospheric CO₂ increase on the potential yield of wheat in Merguellil catchment (Tunisia) under “present”, “future” and “extreme weather” climate conditions.

Irrigation strategy	Yield 2000 (*)	Yield 2050 (*)		Yield 2050 wp_adj (**)		Yield 2050 late_var (*)		Yield 2050+1 (*)		Yield 2050+1 wp_adj (**)		Yield 2050+1 late_var (*)	
	(t/ha)	(t/ha)	var.% (2000)	(t/ha)	var.% (2000)	(t/ha)	var.% (2000)	(t/ha)	var.% (2000)	(t/ha)	var.% (2000)	(t/ha)	var.% (2000)
full	6.4	6.1	-4.6%	7.4	14.5%	6.9	7.6%	6.0	-6.8%	7.2	11.8%	6.7	5.1%
mild1	6.1	5.6	-8.2%	6.7	10.2%	6.3	2.9%	5.7	-7.4%	6.8	11.2%	6.3	3.9%
mild2	5.5	5.2	-4.5%	6.3	14.6%	5.8	6.1%	5.0	-8.0%	6.0	10.4%	5.6	2.2%
medium	5.1	4.3	-16.2%	5.1	0.6%	4.8	-6.3%	4.6	-10.3%	5.5	7.6%	5.1	0.2%
severe1	4.4	4.0	-7.6%	4.8	10.9%	4.4	1.8%	3.9	-9.7%	4.7	8.4%	4.4	-0.1%
severe2	3.3	2.9	-12.8%	3.4	4.6%	3.1	-5.0%	2.9	-12.7%	3.4	4.7%	3.1	-4.6%
rainfed	1.9	1.8	-5.3%	2.1	13.7%	1.9	-0.7%	1.6	-17.1%	1.9	-0.5%	1.6	-12.1%
(*) assuming wp (2000) = 1 (kg/m ³)													
(**) assuming wp (2050) = wp(2000)*1.2 = 1.2 (kg/m ³)													

Tab. 57 – Effect of planting date, variety selection and atmospheric CO₂ increase on the potential yield of wheat in Merguellil catchment (Tunisia) under “present”, “future” and “extreme weather” climate conditions.

Irrigation strategy	Yield 2000 (*)	Yield 2050 (*)		Yield 2050 wp_adj (**)		Yield 2050 late_var (*)		Yield 2050+1 (*)		Yield 2050+1 wp_adj (**)		Yield 2050+1 late_var (*)	
	(t/ha)	(t/ha)	var.% (2000)	(t/ha)	var.% (2000)	(t/ha)	var.% (2000)	(t/ha)	var.% (2000)	(t/ha)	var.% (2000)	(t/ha)	var.% (2000)
october	5.2	4.8	-8.5%	5.7	9.8%	5.5	5.8%	4.6	-10.9%	5.6	6.9%	5.3	1.4%
november	6.1	5.7	-6.8%	6.8	11.8%	6.5	6.5%	5.4	-10.5%	6.5	7.4%	6.2	2.1%
december	6.7	6.4	-4.1%	7.7	15.1%	7.2	7.6%	6.2	-7.6%	7.4	10.9%	7.0	4.3%
january	6.9	6.6	-3.2%	8.0	16.1%	7.4	8.4%	6.5	-5.2%	7.8	13.8%	7.3	6.2%
february	7.3	7.2	-1.5%	8.6	18.2%	7.9	9.1%	7.2	-1.5%	8.6	18.1%	8.0	10.1%
average	6.4	6.1	-4.6%	7.4	14.5%	6.9	7.6%	6.0	-6.8%	7.2	11.8%	6.7	5.1%
(*) assuming wp (2000) = 1 (kg/m ³)													
(**) assuming wp (2050) = wp(2000)*1.2 = 1.2 (kg/m ³)													

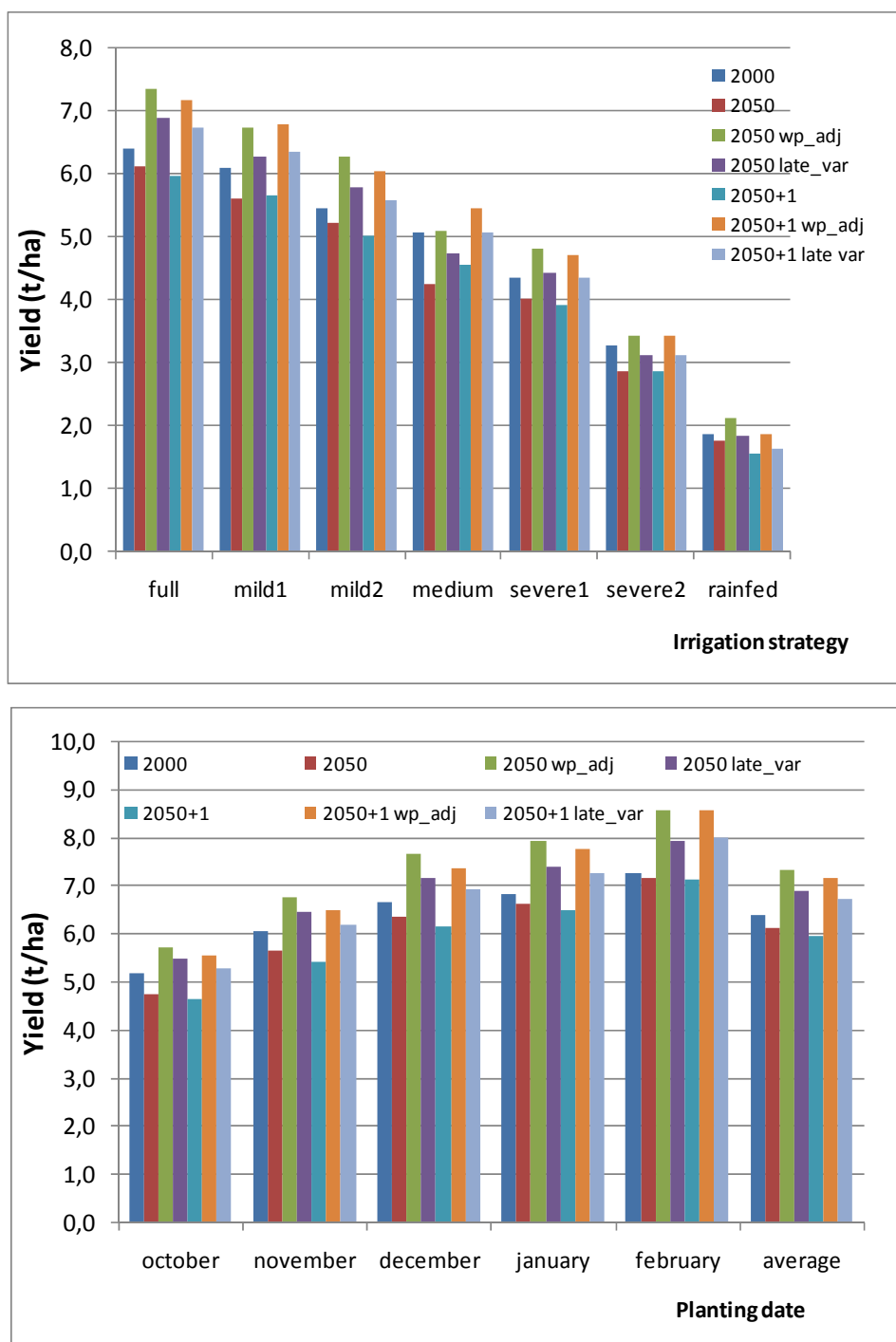


Fig. 41 – Effect of planting date, irrigation strategies, variety selection and atmospheric CO₂ increase on potential yield of wheat in Merguellil catchment (Tunisia) under “present”, “future” and “extreme weather (2050+1)” climate conditions.

4.3. Tomato

4.3.1. Cycle length and crop coefficient curves

The effect of temperature increase (and relative GDD accumulation) on current and projected crop cycle length and corresponding crop coefficient curves is represented in the following graphs, and the following observations have to be highlighted:

- if varietal adaptation is not considered, an important reduction of the total growing cycle is predicted for all planting dates, because of the faster accumulation of the required GGD sum under “future” climate conditions (2050) (fig. 42-43);
- if a late maturing variety will be used, the total crop cycle length (2050 late_var) is projected to remain relatively the same as for the current variety under “present” climate conditions (2000), especially for late planting dates (fig. 43);
- with respect to the four crop coefficient stages, a relative reduction is predicted in proportion to the corresponding increase in the cumulative GDD (lower during winter, higher during spring-summer months), but with a greater effect in the case of early (February) rather than late (April) planting dates (fig. 42).

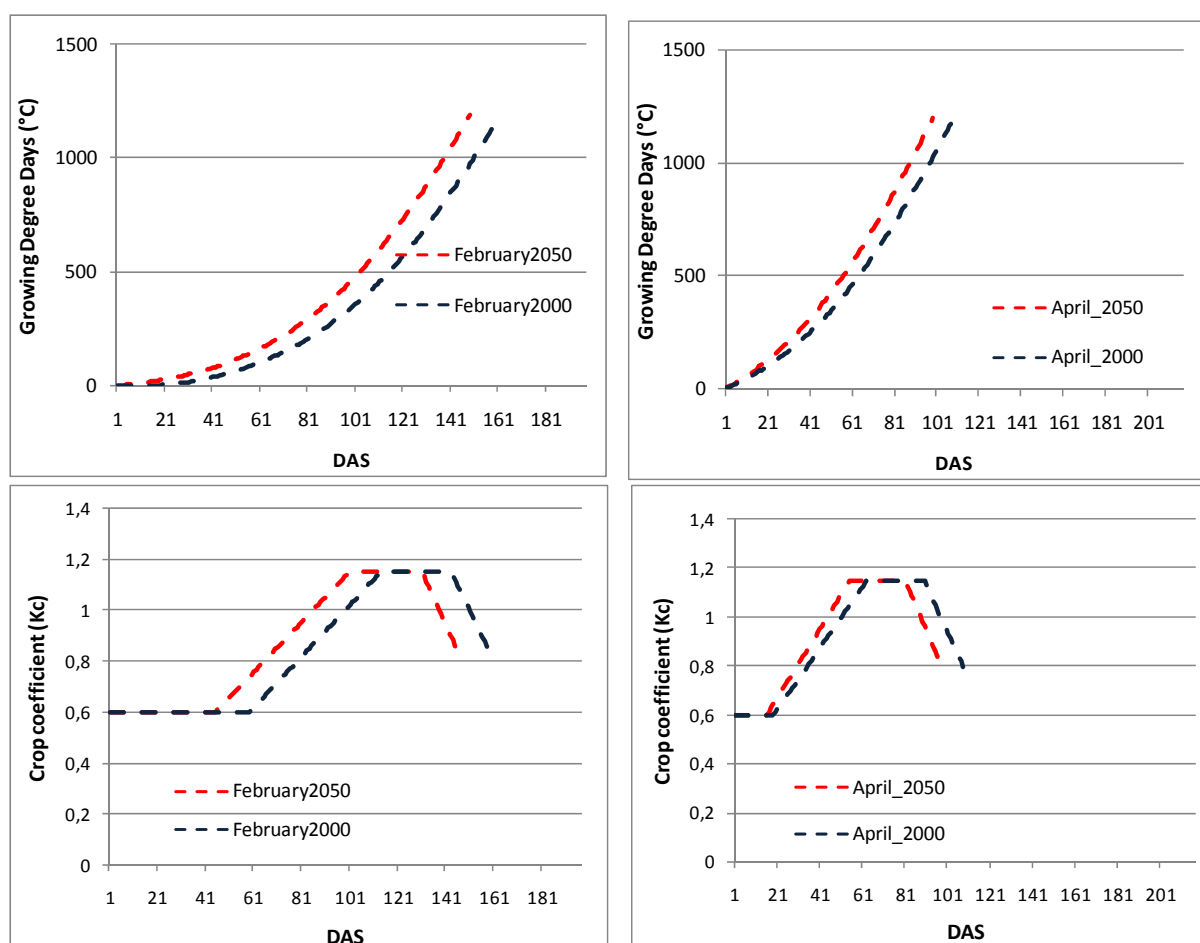


Fig. 42 – Predicted cumulative GDD and corresponding Kc curves for tomato in Merguellil catchment (Tunisia) as affected by different planting dates and climate scenarios.

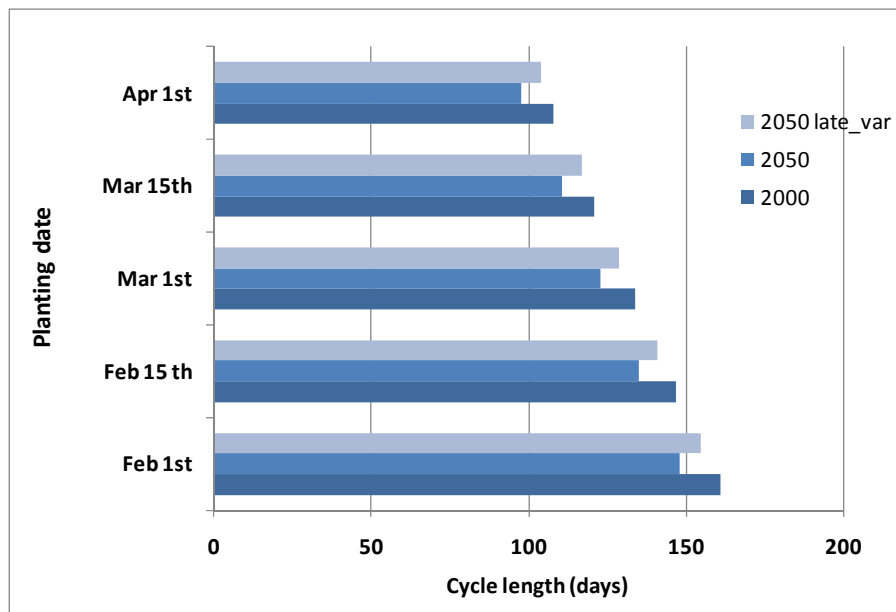


Fig. 43 – Length of total growing cycle of tomato in Merguellil catchment (Tunisia) as affected by planting date, variety selection and climate variations.

4.3.2. Crop evapotranspiration and irrigation requirements

The impact of climate change on maximum and effective crop evapotranspiration as well as on net irrigation requirements, also considering the relative effect of selected adaptation strategies (planting dates, variety selection and deficit irrigation strategies), is summarized in the following tables and graphs. In brief, the following observations are reported:

- maximum seasonal crop evapotranspiration is projected to reduce for the current variety under “future” (2050) scenario as a consequence of the expected shortening of the crop growing cycle, on average of about -3.6% with respect to current conditions (2000) (fig. 45 and tab.58);
- on the contrary, if a late maturing variety (2050 late_var) is selected, maximum evapotranspiration is projected to increase (on average of about +3.2%) for all the planting dates (fig. 45 and tab.58);
- the relative effect of the projected decrease of rainfall patterns seems to be less relevant for the crop water balance, because of their very low values (tab.59);
- maximum seasonal crop evapotranspiration is observed always to decrease slightly (in absolute terms) for late (April) planting date with respect to earlier (February) ones, because of the shifting of the cycle towards the higher summer temperatures and the corresponding reduction in the total length (fig. 45 and tab.58);
- effective seasonal crop evapotranspiration and net irrigation requirements are both highly dependent on the irrigation strategy, progressively reducing going from full irrigation to rainfed conditions (fig. 45 and tab.60-61);
- as for ET_{c_max} , also the ET_{c_eff} and NIR are projected to decrease in 2050 if the current variety is used; on the other side, if a late maturing variety is selected, NIR and ET_{c_eff} are always projected to increase (fig. 45 and tab.60-61).

Tab. 58 – Effect of planting date and variety selection on the maximum crop evapotranspiration of tomato in Merguellil catchment (Tunisia) under “present” and “future” climate conditions.

Planting date	ETc_max 2000	ETc_max 2050		ETc_max 2050 late_var	
	[mm/season]	[mm/season]	(variation vs 2000)	[mm/season]	(variation vs 2000)
February 1st	814.1	785.0	-3.6%	841.4	3.3%
February 15th	791.7	761.6	-3.8%	812.2	2.6%
March 1st	769.5	741.5	-3.6%	793.4	3.1%
March 15th	737.9	715.9	-3.0%	766.0	3.8%
April 1st	707.8	680.8	-3.8%	732.1	3.4%
average	764.2	737.0	-3.6%	789.0	3.2%

Tab. 59 – Effect of planting date and variety selection on the effective rainfall pattern during crop cycle of tomato in Merguellil catchment (Tunisia) under “present” and “future” climate conditions.

Planting date	Rain_eff 2000	Rain_eff 2050		Rain_eff 2050 late_var	
	[mm/season]	[mm/season]	(variation vs 2000)	[mm/season]	(variation vs 2000)
February 1st	81.6	66.6	-18.4%	68.8	-15.6%
February 15th	70.5	55.2	-21.7%	57.4	-18.5%
March 1st	58.8	50.4	-14.4%	52.6	-10.6%
March 15th	47.2	31.1	-34.1%	33.3	-29.3%
April 1st	34.0	20.8	-38.9%	20.8	-38.9%
average	58.4	44.8	-23.3%	46.6	-20.2%

Tab. 60 – Effect of irrigation strategies and variety selection on the effective evapotranspiration of tomato in Merguellil catchment (Tunisia) under “present” and “future” climate.

Irrigation strategy	ETc_eff 2000	ETc_eff 2050		ETc_eff 2050 late_var	
	[mm/season]	[mm/season]	(variation vs 2000)	[mm/season]	(variation vs 2000)
full	763.5	735.6	-3.7%	787.6	3.2%
mild1	726.4	699.2	-3.7%	745.3	2.6%
mild2	658.6	632.5	-4.0%	674.8	2.5%
medium	637.6	609.9	-4.3%	653.5	2.5%
severe1	536.7	514.4	-4.2%	544.6	1.5%
severe2	407.9	387.7	-5.0%	410.1	0.5%
rainfed	177.5	164.8	-7.1%	166.0	-6.5%

Tab. 61 – Effect of irrigation strategies and variety selection on the net irrigation requirements of tomato in Merguellil catchment (Tunisia) under “present” and “future” climate conditions.

Irrigation strategy	NIR 2000	NIR 2050		NIR 2050 late_var	
	[mm/season]	[mm/season]	(variation vs 2000)	[mm/season]	(variation vs 2000)
full	671.1	671.8	0.1%	719.1	7.2%
mild1	625.7	612.2	-2.1%	654.7	4.6%
mild2	536.9	537.5	0.1%	575.3	7.2%
medium	523.4	517.4	-1.2%	552.6	5.6%
severe1	406.7	397.9	-2.1%	425.6	4.6%
severe2	261.7	258.7	-1.2%	276.3	5.6%
rainfed	0.0	0.0	0.0%	0.0	0.0%

- by plotting together the values of seasonal ETc_{eff} and NIR (obtained under different irrigation strategies and variety) for different climate scenarios, there is a clear prediction of their reduction (respectively of about -4.1% and -1%, on average) while, by considering a late maturing variety, only an increase of both is predicted (respectively of about +2.2% and +5.9%, on average) (fig. 44);
- the cumulative curves of ETc_{max} in 2050 (versus 2000) show always (especially for earlier planting dates) a clear shifting towards higher values, thus representing the relative increase in the daily crop water requirements, although with a decrease in the cumulative final value (depending on the anticipated ending of the cycle) (fig.46).

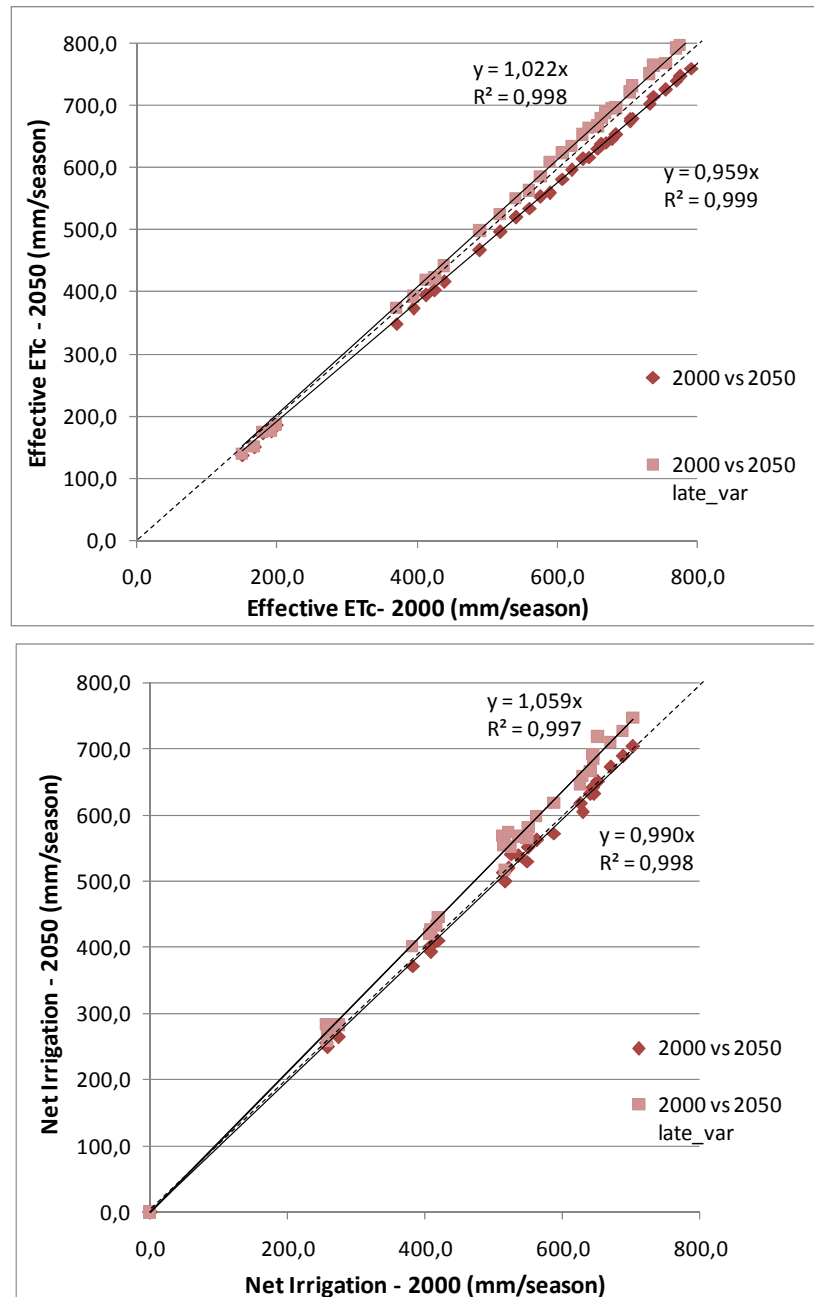


Fig. 44 – Scatter-plot of seasonal crop evapotranspiration and net irrigation requirements of as affected by different variety selection for tomato in Merguellil catchment (Tunisia) under “present” and “future” climate conditions.

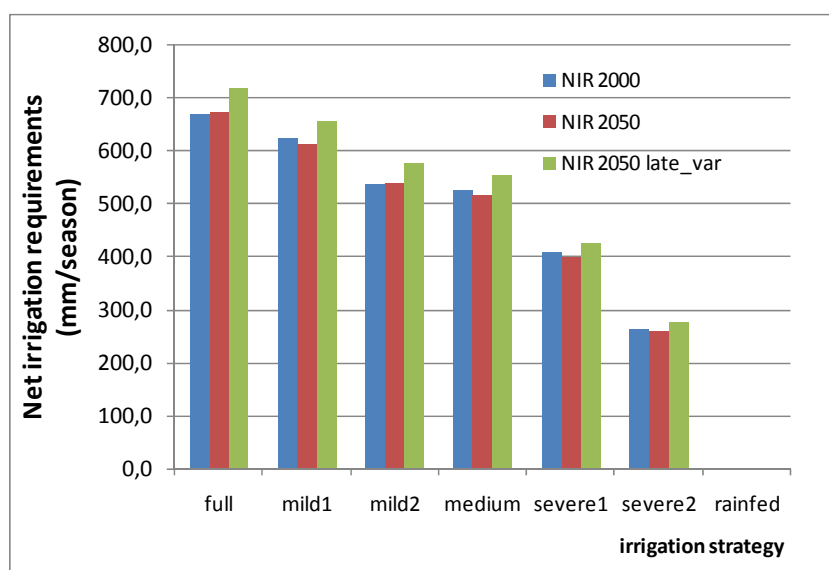
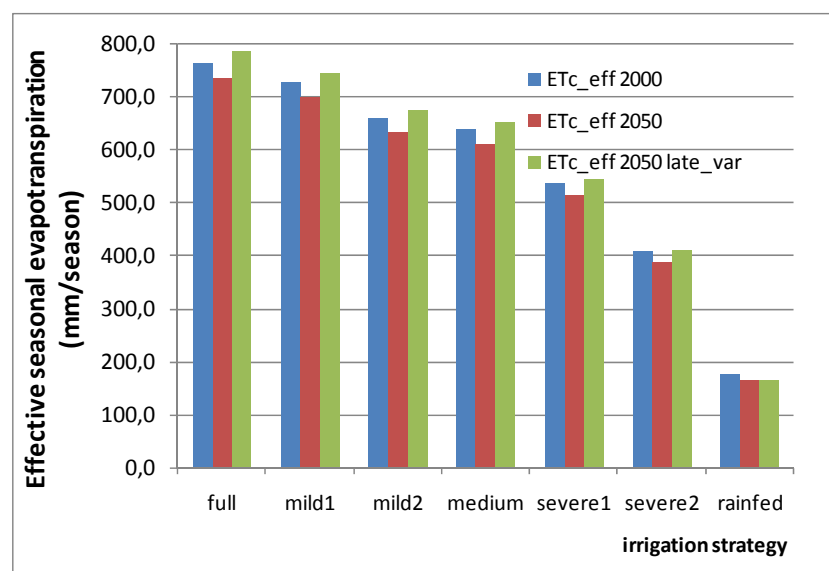
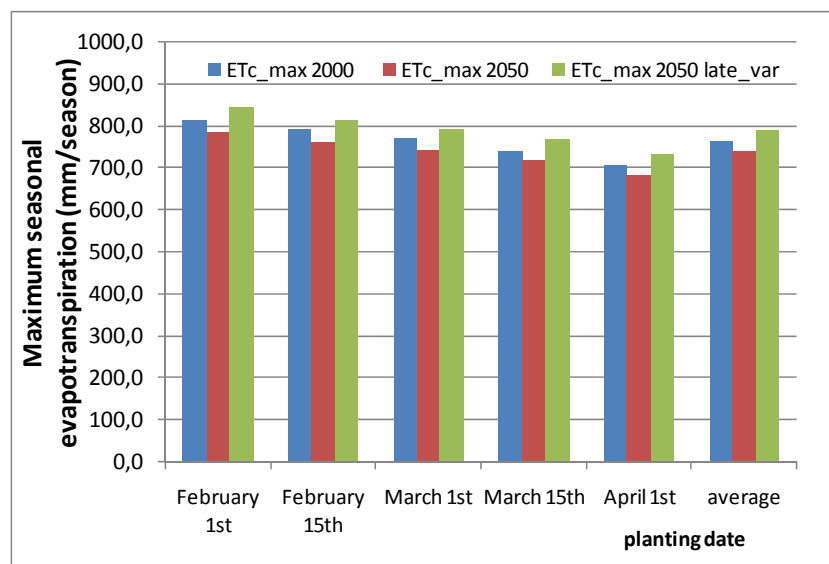


Fig. 45 – Effect of planting date, irrigation strategies and variety selection on maximum and effective crop evapotranspiration and net irrigation requirements of tomato in Merguellil catchment (Tunisia) under “present” and “future” climate conditions.

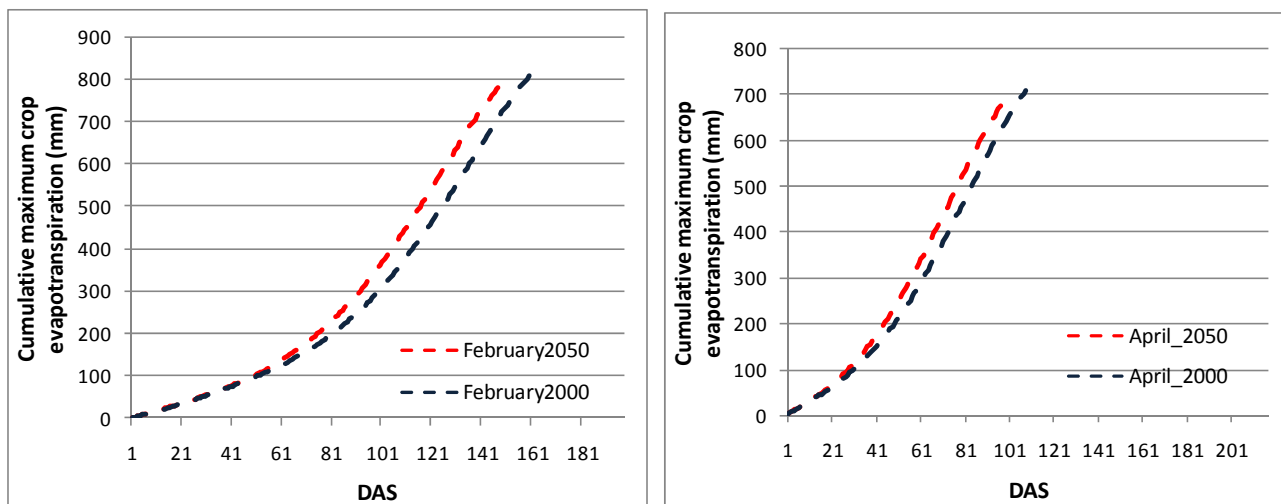


Fig. 46 – Cumulative curves of maximum crop evapotranspiration as affected by different planting date for tomato in Merguellil catchment (Tunisia) under “present” and “future” climate conditions.

4.3.3. Yield response to water

The impact of climate change on potential yield, also considering the relative effect of selected adaptation strategies (planting dates, variety selection and deficit irrigation strategies), is summarized in the following tables and graphs. In brief, the following observations are reported:

- yield is projected to reduce under “future” scenario (2050) with respect to current conditions (2000), on average from 76.4 to 73.7 t ha⁻¹ (about -3.6%), depending on irrigation strategies (tab. 62 and fig. 47) and planting dates (tab.63 and fig) as a consequence of the expected shortening of the crop growing cycle;
- on the contrary, if the expected fertilizing effect due to an increase in atmospheric CO₂ concentration will occur, yield (2050 wp_adj) is projected to increase in quite all conditions (with an average of 88.4 t ha⁻¹, +15.7%), and thus to overcome the effect of the shortening of the crop cycle (fig. 47 and tab.62-63);
- on the other side, if a late maturing variety (2050 late_var) is selected, yield is projected to increase (with an average of 78.9 t ha⁻¹, +3.2%), especially under fully irrigation and late planting dates (fig. 47 and tab.62-63);
- there is a clear reduction in potential yield under increasing water stress conditions (fig.47), but still under “severe” water stress (thus only supported by supplemental irrigations) values of 15-30 t ha⁻¹ are still possible to be reached; in the case of rainfed conditions, according to the model used, no yield is expected in all conditions;
- yield is observed always to slightly decrease (in absolute terms) for late (April) planting date with respect to earlier (February) ones (fig.47), because of the shortening of the growing cycle due to its shifting in the hotter summer.

Tab. 62 – Effect of irrigation strategies, variety selection and atmospheric CO₂ increase on the potential yield of tomato in Merguellil catchment (Tunisia) under “present” and “future” climate conditions.

Irrigation strategy	Yield 2000 (*)	Yield 2050 (*)		Yield 2050 wp_adj (**)		Yield 2050 late_var (*)	
	(t/ha)	(t/ha)	(variation vs 2000)	(t/ha)	(variation vs 2000)	(t/ha)	(variation vs 2000)
full	76.4	73.7	-3.6%	88.4	15.7%	78.9	3.2%
mild1	68.3	65.4	-4.2%	78.5	15.0%	69.4	1.7%
mild2	50.8	48.7	-4.2%	58.5	15.0%	51.8	1.9%
medium	51.8	48.9	-5.6%	58.7	13.3%	52.4	1.0%
severe1	31.0	29.7	-4.2%	35.6	15.0%	31.1	0.4%
severe2	16.0	15.1	-5.7%	18.1	13.1%	15.8	-1.4%
rainfed	0.0	0.0		0.0		0.0	
(*) assuming wp (2000) = 10 (kg/m3)							
(**) assuming wp (2050)= wp(2000)*1.2= 12 (kg/m3)							

Tab. 63 – Effect of planting date, variety selection and atmospheric CO₂ increase on the potential yield of tomato in Merguellil catchment (Tunisia) under “present” and “future” climate conditions.

Irrigation strategy	Yield 2000 (*)	Yield 2050 (*)		Yield 2050 wp_adj (**)		Yield 2050 late_var (*)	
	(t/ha)	(t/ha)	(variation vs 2000)	(t/ha)	(variation vs 2000)	(t/ha)	(variation vs 2000)
Febr 1st	81.4	78.5	-3.6%	94.2	15.7%	84.1	3.3%
Febr 15th	79.2	76.2	-3.8%	91.4	15.4%	81.2	2.6%
March 1st	76.9	74.1	-3.6%	89.0	15.6%	79.3	3.1%
March 15th	73.8	71.6	-3.0%	85.9	16.4%	76.6	3.8%
April 1st	70.8	68.1	-3.8%	81.7	15.4%	73.2	3.4%
average	76.4	73.7	-3.6%	88.4	15.7%	78.9	3.2%
(*) assuming wp (2000) = 10 (kg/m3)							
(**) assuming wp (2050)= wp(2000)*1.2= 12 (kg/m3)							

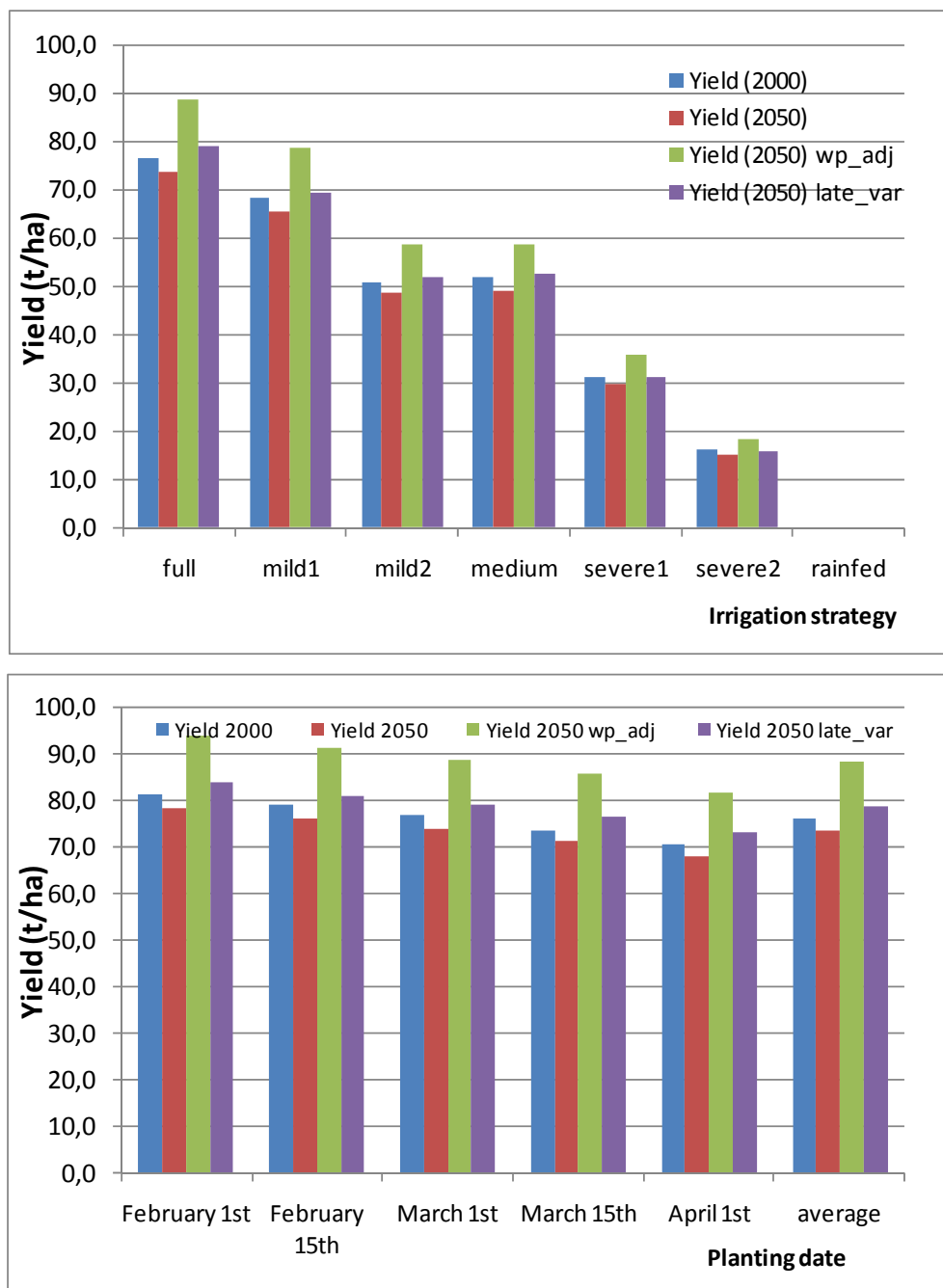


Fig. 47 – Effect of planting date, irrigation strategies, variety selection and atmospheric CO₂ increase on potential yield of tomato in Merguellil catchment (Tunisia) under “present” and “future” climate conditions.

4.4. Potato

4.4.1. Cycle length and crop coefficient curves

The effect of temperature increase (and relative GDD accumulation) on current and projected crop cycle length and corresponding crop coefficient curves is represented in the following graphs, and the following observations have to be highlighted:

- if varietal adaptation is not considered, an important reduction of the total growing cycle is predicted for all planting dates, because of the faster accumulation of the required GGD sum under “future” climate conditions (2050) (fig. 48-49);
- if a late maturing variety will be used, the total crop cycle length (2050 late_var) is projected to remain relatively the same as for the current variety under “present” climate conditions (2000), especially for late planting dates (fig. 49);
- with respect to the four crop coefficient stages, a relative reduction is predicted in proportion to the corresponding increase in the cumulative GDD (lower during winter, higher during spring-summer months), but with a greater effect in the case of early (October) rather than late (February) planting dates (fig. 48).

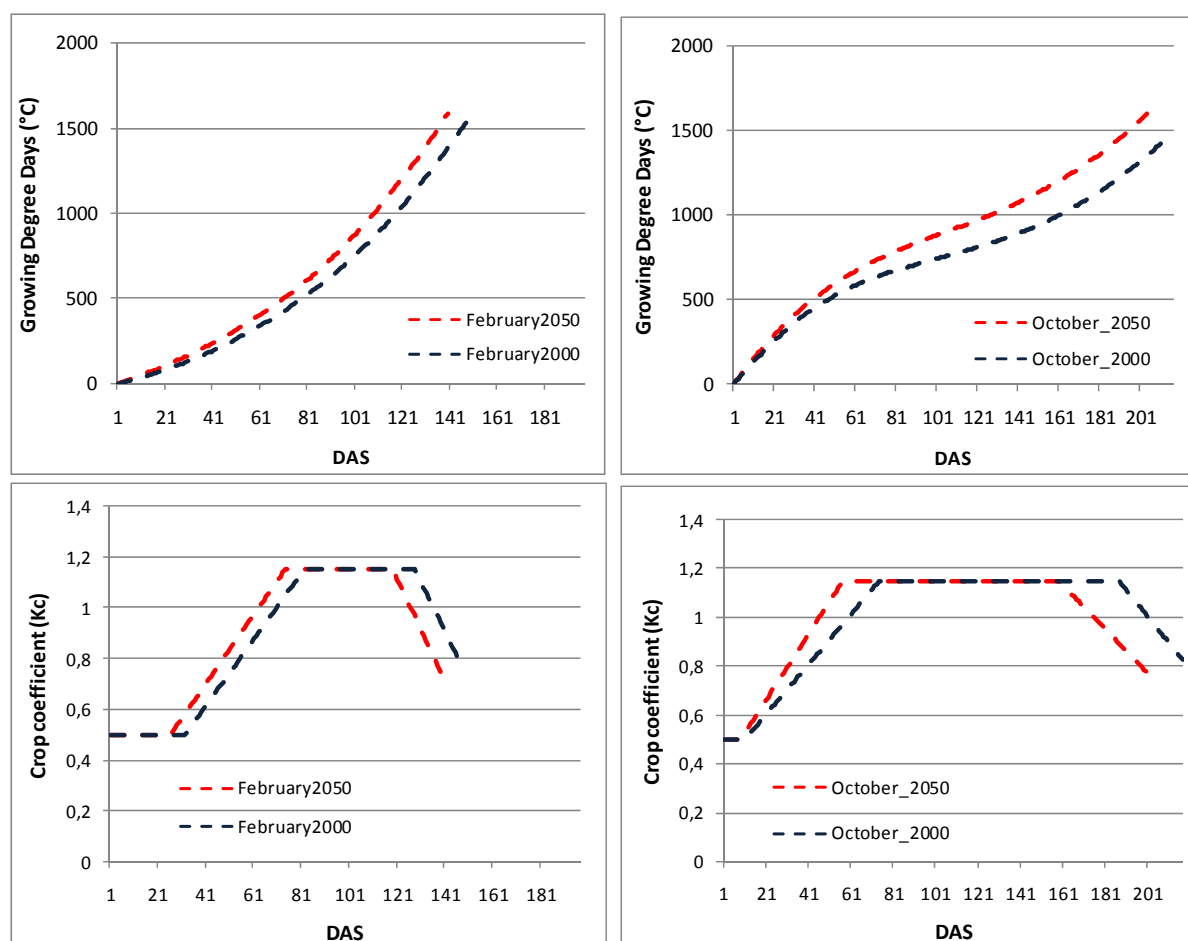


Fig. 48 – Predicted cumulative GDD and corresponding Kc curves for potato in Merguellil catchment (Tunisia) as affected by different planting dates and climate scenarios.

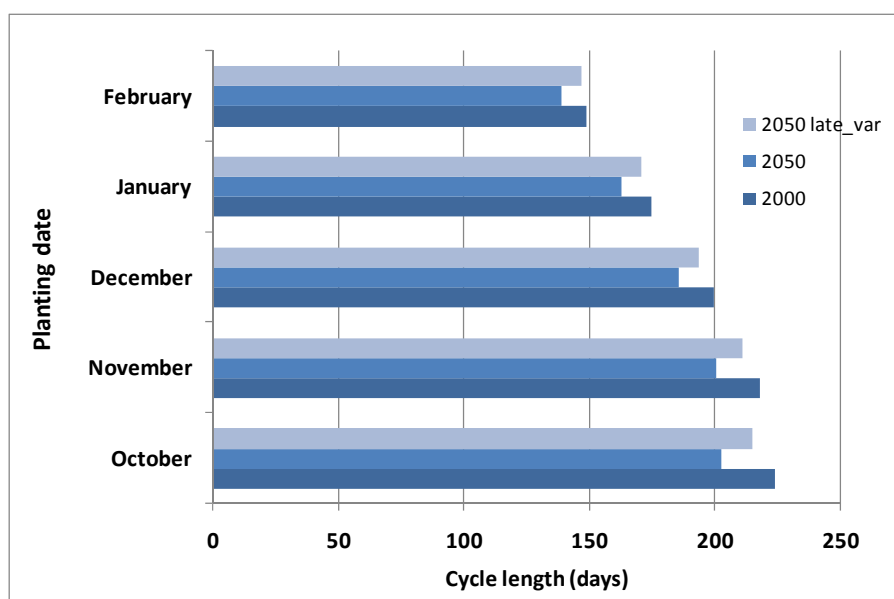


Fig.49 – Length of total growing cycle of potato in Merguellil catchment (Tunisia) as affected by planting date, variety selection and climate variations.

4.4.2. Crop evapotranspiration and irrigation requirements

The impact of climate change on maximum and effective crop evapotranspiration as well as on net irrigation requirements, also considering the relative effect of selected adaptation strategies (planting dates, variety selection and deficit irrigation strategies), is summarized in the following tables and graphs. In brief, the following observations are reported:

- maximum seasonal crop evapotranspiration is projected to reduce for the current variety under “future” (2050) scenario as a consequence of the expected shortening of the crop growing cycle, on average of about -7% with respect to current conditions (2000) (fig. 51 and tab.64);
- on the contrary, if a late maturing variety (2050 late_var) is selected, maximum evapotranspiration is projected to increase (on average of about 2.2%) (fig. 51 and tab.64);
- the relative effect of the projected variation of rainfall patterns seems slightly important for the crop water balance, with an average reduction of about -2.2 mm during cropping cycle (tab.65);
- maximum seasonal crop evapotranspiration is observed always to increase (in absolute terms) towards a peak of planting date of December with respect to earlier and later ones (fig. 51 and tab.64);
- effective seasonal crop evapotranspiration and net irrigation requirements are both highly dependent on the irrigation strategy, progressively reducing going from full irrigation to rainfed conditions (fig. 51 and tab.66-67);
- as for ET_{c_max} , also the ET_{c_eff} and NIR are projected to decrease in 2050 if the current variety is used; on the other side, if a late maturing variety is selected, while ET_{c_eff} is projected to remain relatively stable, NIR is always projected to increase (fig. 51 and tab.66-67).

Tab. 64 – Effect of planting date and variety selection on the maximum crop evapotranspiration of potato in Merguellil catchment (Tunisia) under “present” and “future” climate conditions.

Planting date	ETc_max 2000	ETc_max 2050		ETc_max 2050 late_var	
	[mm/season]	[mm/season]	(variation vs 2000)	[mm/season]	(variation vs 2000)
october	721.2	631.2	-12.5%	705.8	-2.1%
november	793.3	720.3	-9.2%	797.9	0.6%
december	801.5	754.1	-5.9%	820.6	2.4%
january	762.4	727.3	-4.6%	793.9	4.1%
february	751.8	731.1	-2.8%	796.8	6.0%
average	766.0	712.8	-7.0%	783.0	2.2%

Tab. 65 – Effect of planting date and variety selection on the effective rainfall pattern during crop cycle of potato in Merguellil catchment (Tunisia) under “present” and “future” climate conditions.

Planting date	Rain_eff 2000	Rain_eff 2050		Rain_eff 2050 late_var	
	[mm/season]	[mm/season]	(variation vs 2000)	[mm/season]	(variation vs 2000)
october	154.9	136.1	-12.2%	144.0	-7.1%
november	140.3	119.2	-15.0%	121.4	-13.5%
december	122.7	101.1	-17.7%	101.1	-17.7%
january	92.7	75.8	-18.2%	75.8	-18.2%
february	81.6	64.4	-21.1%	66.6	-18.4%
average	118.4	99.3	-16.2%	101.7	-14.1%

Tab. 66 – Effect of irrigation strategies and variety selection on the effective evapotranspiration of potato in Merguellil catchment (Tunisia) under “present” and “future” climate conditions.

Irrigation strategy	ETc_eff 2000	ETc_eff 2050		ETc_eff 2050 late_var	
	[mm/season]	[mm/season]	(variation vs 2000)	[mm/season]	(variation vs 2000)
full	763.8	710.5	-7.0%	779.9	2.1%
mild1	714.8	664.8	-7.0%	728.1	1.9%
mild2	655.5	609.1	-7.1%	664.8	1.4%
medium	633.1	585.8	-7.5%	638.4	0.8%
severe1	532.3	494.2	-7.2%	535.7	0.6%
severe2	412.0	380.6	-7.6%	407.7	-1.1%
rainfed	190.9	175.4	-8.1%	176.8	-7.4%

Tab. 67 – Effect of irrigation strategies and variety selection on the net irrigation requirements of potato in Merguellil catchment (Tunisia) under “present” and “future” climate conditions.

Irrigation strategy	NIR 2000	NIR 2050		NIR 2050 late_var	
	[mm/season]	[mm/season]	(variation vs 2000)	[mm/season]	(variation vs 2000)
full	637.5	600.4	-5.8%	665.6	4.4%
mild1	576.7	539.5	-6.5%	604.2	4.8%
mild2	510.0	480.4	-5.8%	532.5	4.4%
medium	485.5	455.6	-6.2%	507.5	4.5%
severe1	374.8	350.7	-6.5%	392.7	4.8%
severe2	242.7	227.8	-6.2%	253.8	4.5%
rainfed	0.0	0.0	0.0%	0.0	0.0%

- by plotting together the values of seasonal ETc_{eff} and NIR (obtained under different irrigation strategies and variety) for different climate scenarios, there is a clear prediction of their reduction (respectively of about -7.2% and -5.9%, on average) and, also by considering a late maturing variety, a relative stability or slight increase of both is predicted (respectively of about 1.1% and 4.7%, on average) (fig.50);
- the cumulative curves of ETc_{max} in 2050 (versus 2000) show always a clear shifting towards higher values, thus representing the relative increase in the daily crop water requirements, although with a decrease in the cumulative final value (depending on the anticipated ending of the cycle) (fig.52).

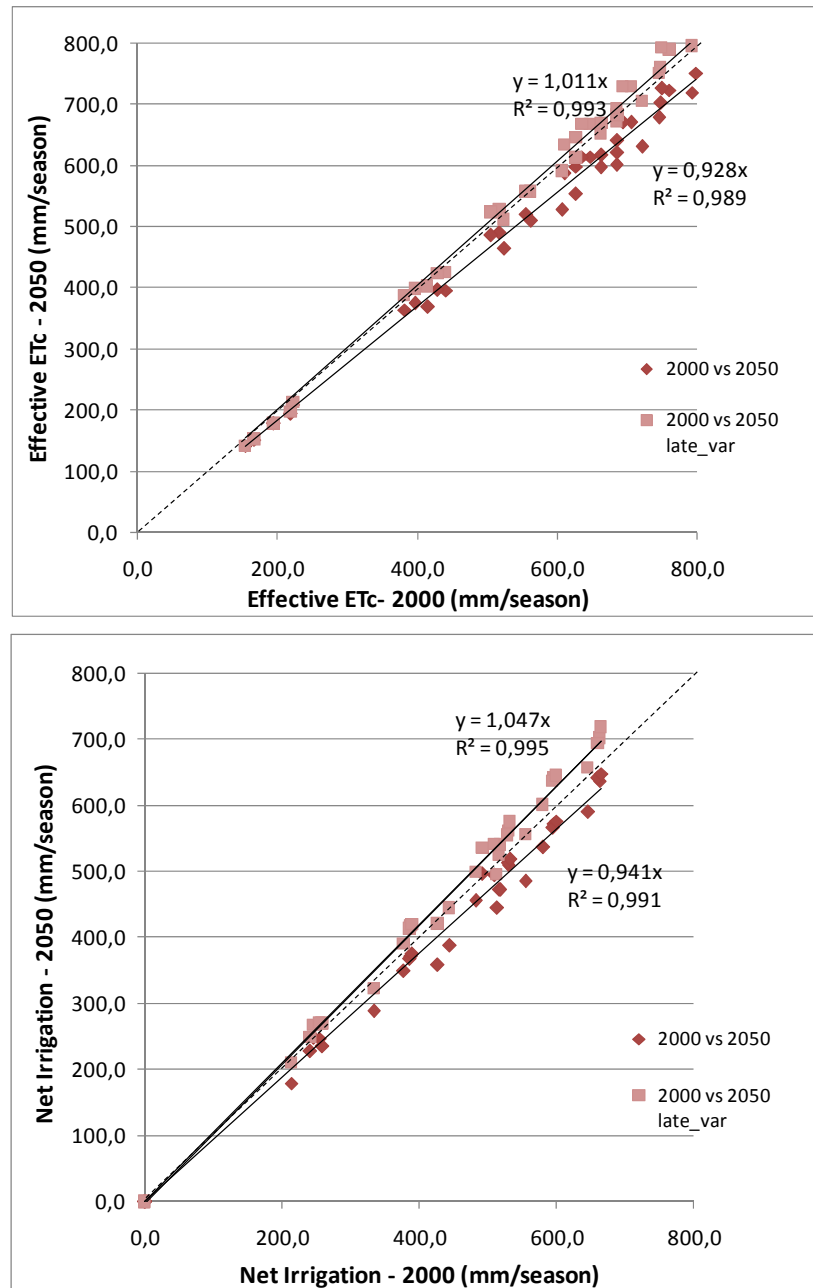


Fig.50 – Scatter-plot of seasonal crop evapotranspiration and net irrigation requirements of as affected by different variety selection for potato in Merguellil catchment (Tunisia) under “present” and “future” climate conditions.

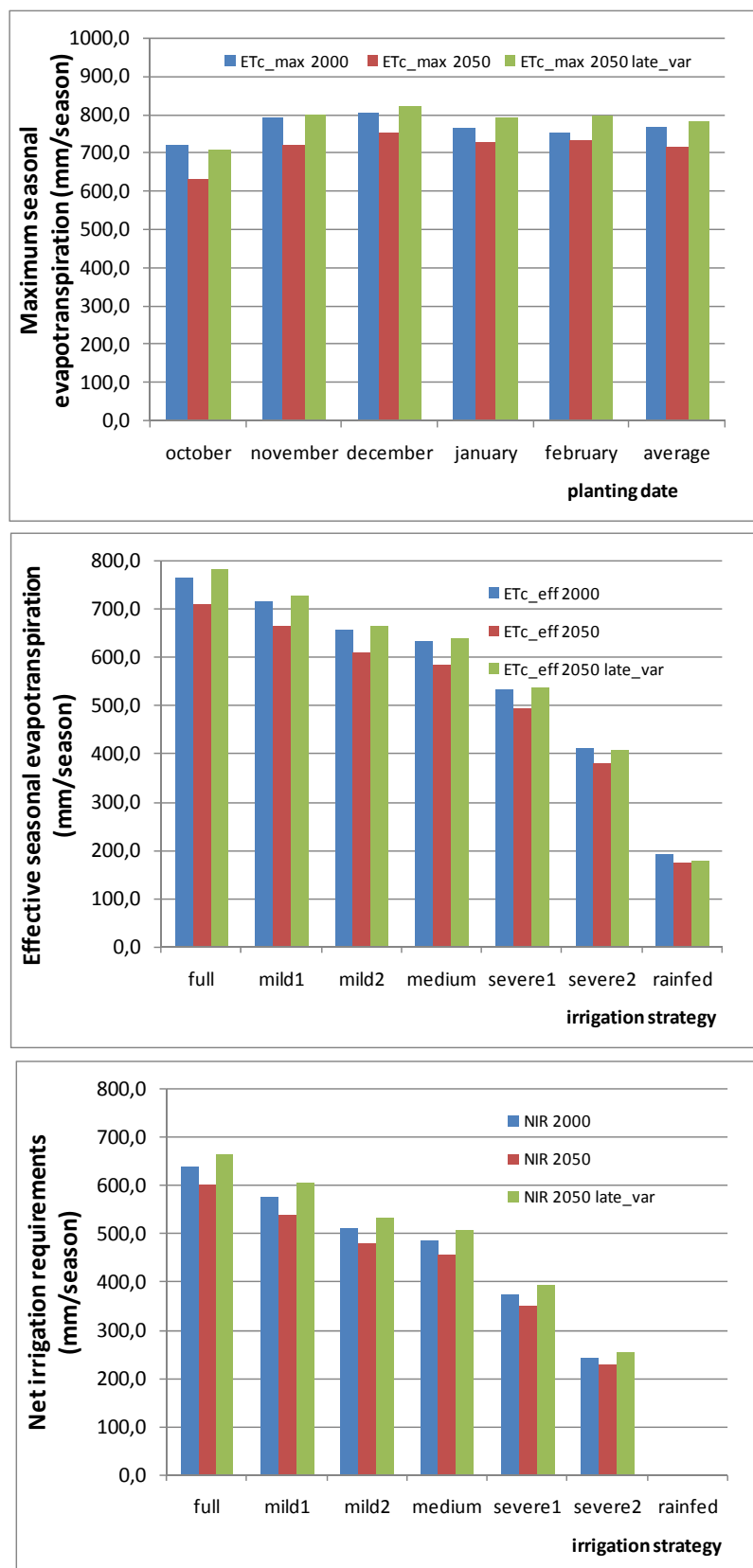


Fig. 51 – Effect of planting date, irrigation strategies and variety selection on maximum and effective crop evapotranspiration and net irrigation requirements of potato in Merguellil catchment (Tunisia) under “present” and “future” climate conditions.

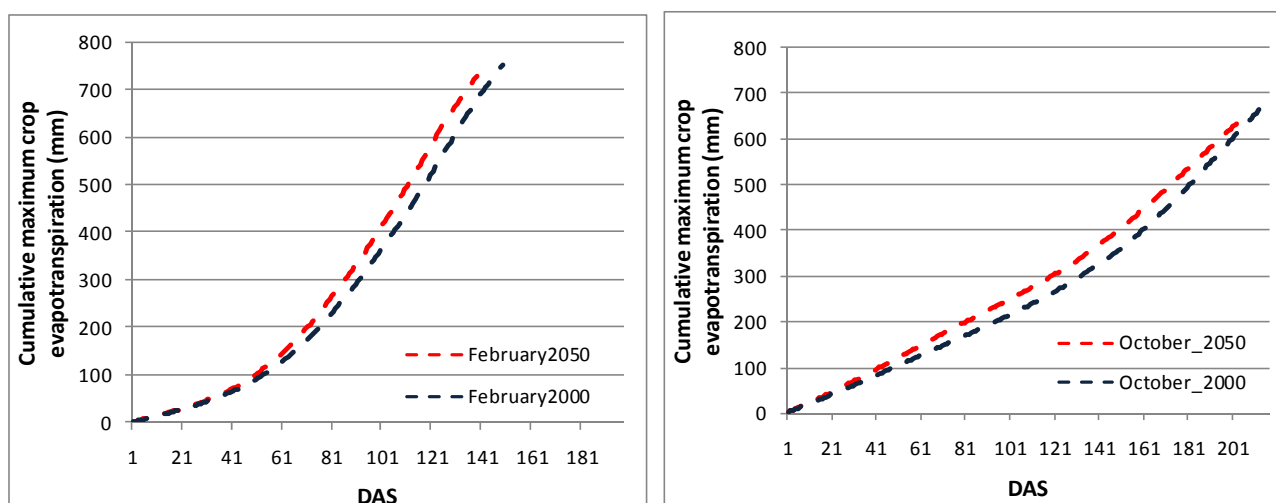


Fig. 52 – Cumulative curves of maximum crop evapotranspiration as affected by different planting date for potato in Merguellil catchment (Tunisia) under “present” and “future” climate conditions.

4.4.3. Yield response to water

The impact of climate change on potential yield, also considering the relative effect of selected adaptation strategies (planting dates, variety selection and deficit irrigation strategies), is summarized in the following tables and graphs. In brief, the following observations are reported:

- yield is projected to reduce under “future” scenario (2050) with respect to current conditions (2000), on average from 38.3 to 35.6 t ha⁻¹ (about -7%), depending on irrigation strategies (tab. 68 and fig.) and planting dates (tab. 69 and fig.53) as a consequence of the expected shortening of the crop growing cycle;
- on the contrary, if the expected fertilizing effect due to an increase in atmospheric CO₂ concentration will occur, yield (2050 wp_adj) is projected to increase in quite all conditions (with an average of 42.8 t ha⁻¹, +11.7%), and thus to overcome the effect of the shortening of the crop cycle (fig. 53 and tab.68-69);
- on the other side, if a late maturing variety (2050 late_var) is selected, yield is projected to slightly increase (with an average of 39.1 t ha⁻¹, 2.2%), depending on irrigation strategy and planting dates (fig. 53 and tab.68-69);
- there is a clear reduction in potential yield under increasing water stress conditions (fig.53), and under “severe” water stress (thus only supported by supplemental irrigations) values of 15-25 t ha⁻¹ are predicted; in the case of rainfed conditions, very low yield (around 8 t ha⁻¹) is expected in all conditions;
- yield is observed always to increase (in absolute terms) for winter planting dates with respect to earlier (October) ones (fig.53), because of the corresponding increase in total maximum crop evapotranspiration.

Tab. 68 – Effect of irrigation strategies, variety selection and atmospheric CO₂ increase on the potential yield of potato in Merguellil catchment (Tunisia) under “present” and “future” climate conditions.

Irrigation strategy	Yield 2000 (*) (t/ha)	Yield 2050 (*)		Yield 2050 wp_adj (**)		Yield 2050 late_var (*)	
		(t/ha)	(variation vs 2000)	(t/ha)	(variation vs 2000)	(t/ha)	(variation vs 2000)
full	38.3	35.6	-7.0%	42.8	11.7%	39.1	2.2%
mild1	34.8	32.5	-6.7%	39.0	11.9%	35.5	1.8%
mild2	30.8	28.8	-6.5%	34.6	12.2%	31.2	1.4%
medium	29.0	27.2	-6.0%	32.7	12.8%	29.5	2.0%
severe1	22.9	21.6	-5.5%	25.9	13.4%	23.1	1.1%
severe2	16.4	15.6	-4.6%	18.7	14.5%	16.5	0.8%
rainfed	7.6	7.5	-2.2%	9.0	17.4%	7.6	-1.0%
(*) assuming wp (2000) = 5 (kg/m3)							
(**) assuming wp (2050)= wp(2000)*1.2= 6 (kg/m3)							

Tab. 69 – Effect of planting date, variety selection and atmospheric CO₂ increase on the potential yield of potato in Merguellil catchment (Tunisia) under “present” and “future” climate conditions.

Irrigation strategy	Yield 2000 (*) (t/ha)	Yield 2050 (*)		Yield 2050 wp_adj (**)		Yield 2050 late_var (*)	
		(t/ha)	(variation vs 2000)	(t/ha)	(variation vs 2000)	(t/ha)	(variation vs 2000)
october	36.1	31.6	-12.5%	37.9	5.0%	35.3	-2.1%
november	39.7	36.0	-9.2%	43.2	9.0%	39.9	0.6%
december	40.1	37.7	-5.9%	45.2	12.9%	41.0	2.4%
january	38.1	36.4	-4.6%	43.6	14.5%	39.7	4.1%
february	37.6	36.6	-2.8%	43.9	16.7%	39.8	6.0%
average	38.3	35.6	-7.0%	42.8	11.7%	39.1	2.2%
(*) assuming wp (2000) = 5 (kg/m3)							
(**) assuming wp (2050)= wp(2000)*1.2= 6 (kg/m3)							

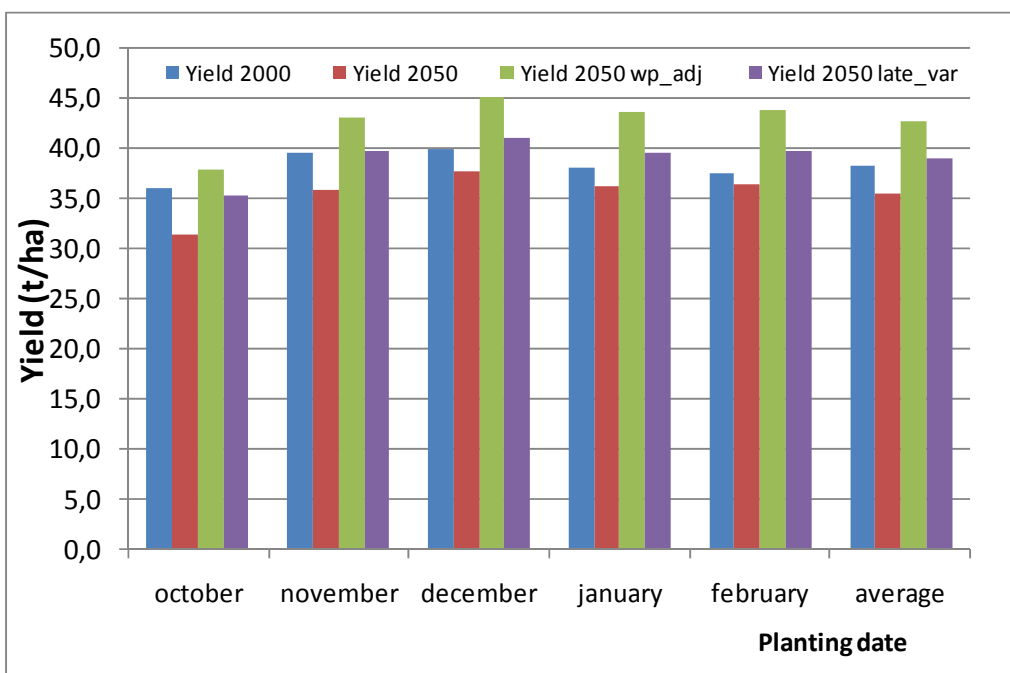
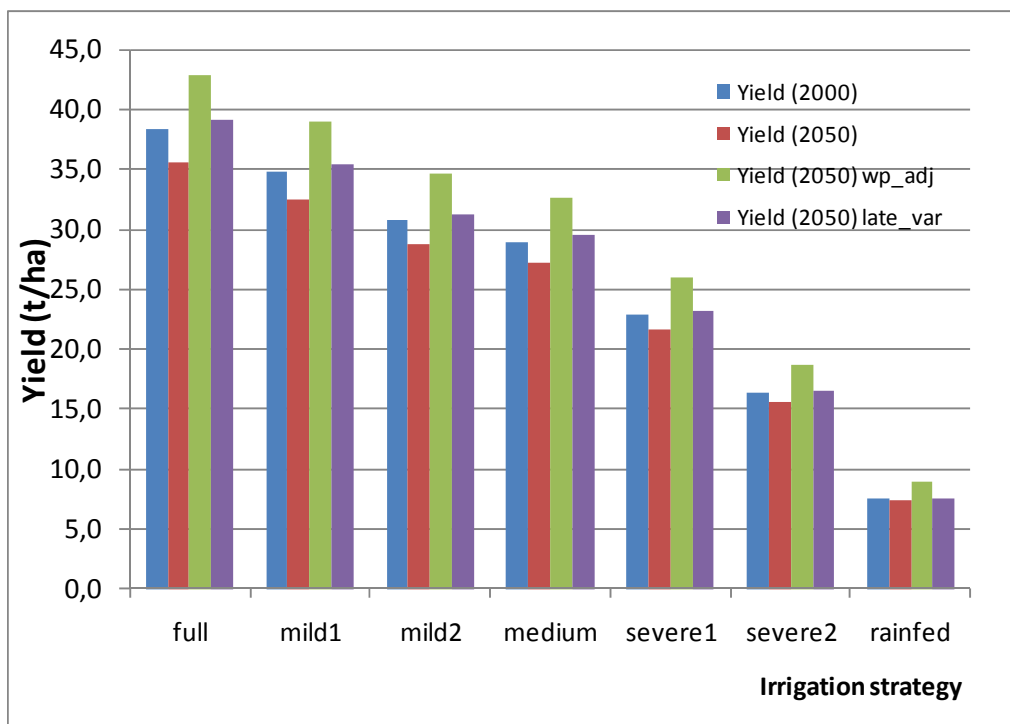


Fig. 53 – Effect of planting date, irrigation strategies, variety selection and atmospheric CO₂ increase on potential yield of potato in Merguellil catchment (Tunisia) under “present” and “future” climate conditions.

4.5. Olive

4.5.1. Cycle length and crop coefficient curves

The effect of temperature increase (and relative GDD accumulation) on current and projected crop cycle of olive has not been evaluated, because of the lack of sufficient information and data to model the relative length of the stages. Thus, a fixed length of the stages and of total growing period has been considered (270 days), as suggested by FAO (2012).

The crop coefficient curves have been modelled by computing the average monthly K_c values according to Orgaz et al. (2006) and FAO (2012) under the different conditions of selected climate scenarios, as affected by the changing of monthly ET_o and rainfall pattern and especially of their relative effect on the evaporative K_c components (from soil and canopy). In table 70, a comparison of the main K_c components is reported, showing the relative reduction of the canopy direct evaporative component (K_{pd}) and of the soil evaporation component ($K_{s,e}$) during the autumn to winter months, due to the projected relative decrease in rainfall pattern and increase in reference evapotranspiration.

In the figure 4, the monthly trends of crop coefficients under different climate scenarios are reported, as computed according to Orgaz et. (2006) for a “new” and an “old” type of olive crop plantation, and in comparison to the fixed K_c coefficient suggested by FAO (2012) for an arid environment; the following observations are reported:

- there is a clear effect of the type of plantation on K_c values, being higher for “new” types of cropping systems under all climate scenarios;
- as yet mentioned, the K_c values for autumn-winter months progressively reduce because of the reduction in projected ET_o and rainfall patterns;
- only slight variations are observed during the spring-summer months, where the K_{pd} and $K_{s,e}$ components reduce close to zero and no variations are observed between scenarios.

Tab. 70 - Comparison of monthly K_c values and main components for olive in Merguellil catchment (Tunisia) under “present”, “future” and “extreme weather” climate conditions.

	Kc			Kc.tr	Kpd			Ks.e		
Month	2000	2050	2050+1	Avg	2000	2050	2050+1	2000	2050	2050+1
1	0.80	0.65	0.59	0.26	0.09	0.05	0.04	0.39	0.28	0.24
2	0.61	0.61	0.56	0.27	0.04	0.04	0.03	0.23	0.23	0.19
3	0.51	0.52	0.49	0.29	0.02	0.03	0.02	0.14	0.14	0.12
4	0.50	0.47	0.45	0.33	0.02	0.01	0.01	0.09	0.07	0.05
5	0.45	0.45	0.45	0.38	0.01	0.00	0.00	0.00	0.00	0.00
6	0.52	0.52	0.52	0.46	0.00	0.00	0.00	0.00	0.00	0.00
7	0.52	0.52	0.52	0.46	0.00	0.00	0.00	0.00	0.00	0.00
8	0.50	0.51	0.50	0.44	0.01	0.01	0.01	0.00	0.00	0.00
9	0.52	0.49	0.47	0.40	0.01	0.01	0.01	0.05	0.02	0.01
10	0.67	0.68	0.64	0.44	0.03	0.03	0.02	0.15	0.15	0.12
11	0.81	0.80	0.73	0.40	0.06	0.06	0.04	0.29	0.28	0.23
12	0.81	0.79	0.69	0.26	0.10	0.09	0.06	0.40	0.39	0.31

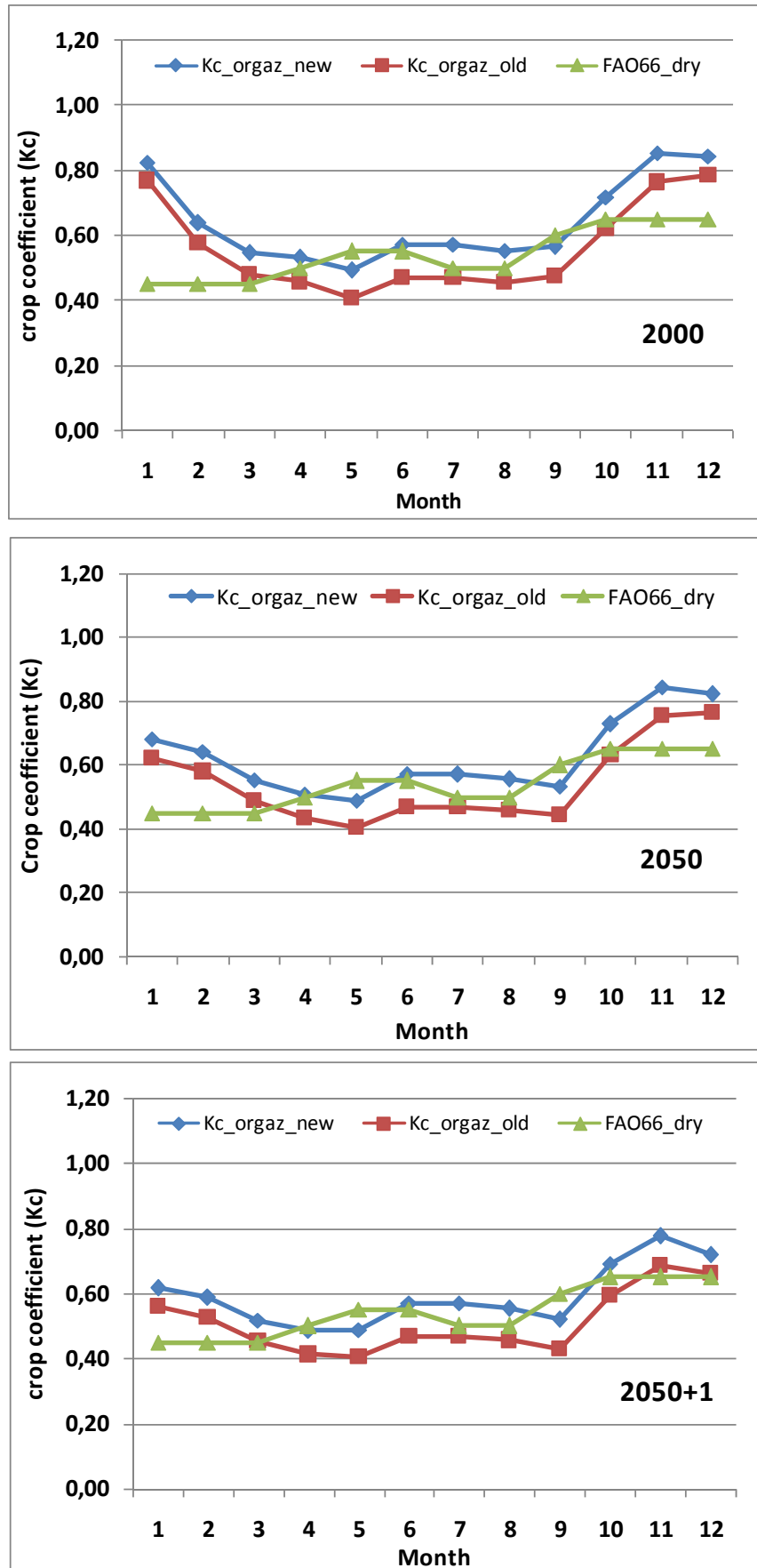


Fig. 54 - Trends of monthly Kc coefficients for olive in Merguellil catchment (Tunisia) under “present”, “future” and “extreme weather” climate conditions.

4.5.2. Crop evapotranspiration and irrigation requirements

The impact of climate change on maximum and effective crop evapotranspiration as well as on net irrigation requirements, also considering the relative effect of selected adaptation strategies (deficit irrigation strategies), is summarized in the following tables and graphs. In brief, the following observations are reported:

- maximum seasonal crop evapotranspiration is projected to increase for all crop models under “future” (2050) scenario, because of the fixed duration of cycle length and probably as a consequence of the expected increase in daily ET_0 , on average of about +4.9% with respect to current conditions (2000) (fig. 55 and tab. 71);
- if “extreme weather” conditions (2050+1) are considered, the projected maximum evapotranspiration variation is slightly lower (on average of about +4.6%), but with some differences between the models (fig. 55 and tab.71);
- the higher values of maximum seasonal crop evapotranspiration are observed for the “new” cropping type, under all climate scenarios (fig. 55 and tab.71);
- the relative effect of the projected increase and/or decrease of rainfall patterns (during the period March-November), seems to be relatively important for the crop water balance, especially under “extreme weather” scenario (about -50 mm), and with respect to the impact for the rainfed strategy (in which rain is the only source of water);
- ET_{c_eff} and NIR are both highly dependent on the irrigation strategy, progressively reducing going from full irrigation to rainfed conditions, under all climate scenarios (fig.55 and tab. 73-74);
- ET_{c_eff} is projected to increase under both 2050 (on average +5.4%) and 2050+1 (+2.7%) scenarios, for all irrigation strategies with the exception of rainfed conditions (-2.1% and -16.4%), in which a reduction is projected because of the reduction of the rainfall patterns, especially under “extreme weather” scenario;
- as a consequence, NIR is projected to increase for all irrigation strategies under both 2050 (on average +10%) and 2050+1 (+14.2%) scenarios.

Tab. 71 – Maximum crop evapotranspiration as estimated by different Kc models for olive in Merguellil catchment (Tunisia) under “present”, “future” and “extreme weather” climate conditions.

Crop model	ETc_max 2000	ETc_max 2050		ETc_max 2050 +1	
	[mm/season]	[mm/season]	(variation vs 2000)	[mm/season]	(variation vs 2000)
Old_Orgaz_270	828.3	860.6	3.9%	841.9	1.6%
New_Orgaz_270	969.3	1010.9	4.3%	996.4	2.8%
FAO66_270	835.8	891.9	6.7%	916.7	9.7%
average	877.8	921.1	4.9%	918.3	4.6%

Tab. 72 – Effective rainfall pattern during crop cycle of olive in Merguellil catchment (Tunisia) under “present”, “future” and “extreme weather” climate conditions.

Crop model	Rain_eff 2000	Rain_eff 2050		Rain_eff 2050 +1	
	[mm/season]	[mm/season]	(variation vs 2000)	[mm/season]	(variation vs 2000)
Old_Orgaz_270	145.1	132.7	-8.5%	92.9	-36.0%
New_Orgaz_270	145.1	132.7	-8.5%	92.9	-36.0%
FAO66_270	145.1	132.7	-8.5%	92.9	-36.0%
average	145.1	132.7	-8.5%	92.9	-36.0%

Tab. 73 – Effect of irrigation strategies on the effective crop evapotranspiration of olive in Merguellil catchment (Tunisia) under “present”, “future” and “extreme weather” climate conditions.

Irrigation strategy	ETc_eff 2000	ETc_eff 2050		ETc_eff 2050+1	
	[mm/season]	[mm/season]	(variation vs 2000)	[mm/season]	(variation vs 2000)
full	877.8	921.1	4.9%	918.3	4.6%
mild1	847.3	885.2	4.5%	880.8	4.0%
mild2	771.8	804.3	4.2%	796.4	3.2%
medium	684.5	746.2	9.0%	717.0	4.8%
severe1	646.3	666.9	3.2%	651.2	0.8%
severe2	466.6	496.0	6.3%	462.7	-0.8%
rainfed	248.0	242.7	-2.1%	207.5	-16.4%

Tab. 74 – Effect of irrigation strategies on the net irrigation requirements of olive in Merguellil catchment (Tunisia) under “present”, “future” and “extreme weather” climate conditions.

Irrigation strategy	NIR 2000	NIR 2050		NIR 2050 +1	
	[mm/season]	[mm/season]	(variation vs 2000)	[mm/season]	(variation vs 2000)
full	685.6	741.2	8.1%	775.8	13.2%
mild1	636.0	669.4	5.3%	715.6	12.5%
mild2	548.5	593.0	8.1%	620.7	13.2%
medium	440.6	513.8	16.6%	514.9	16.9%
severe1	413.4	435.1	5.3%	465.1	12.5%
severe2	220.3	256.9	16.6%	257.5	16.9%
rainfed	0.0	0.0	0.0%	0.0	0.0%

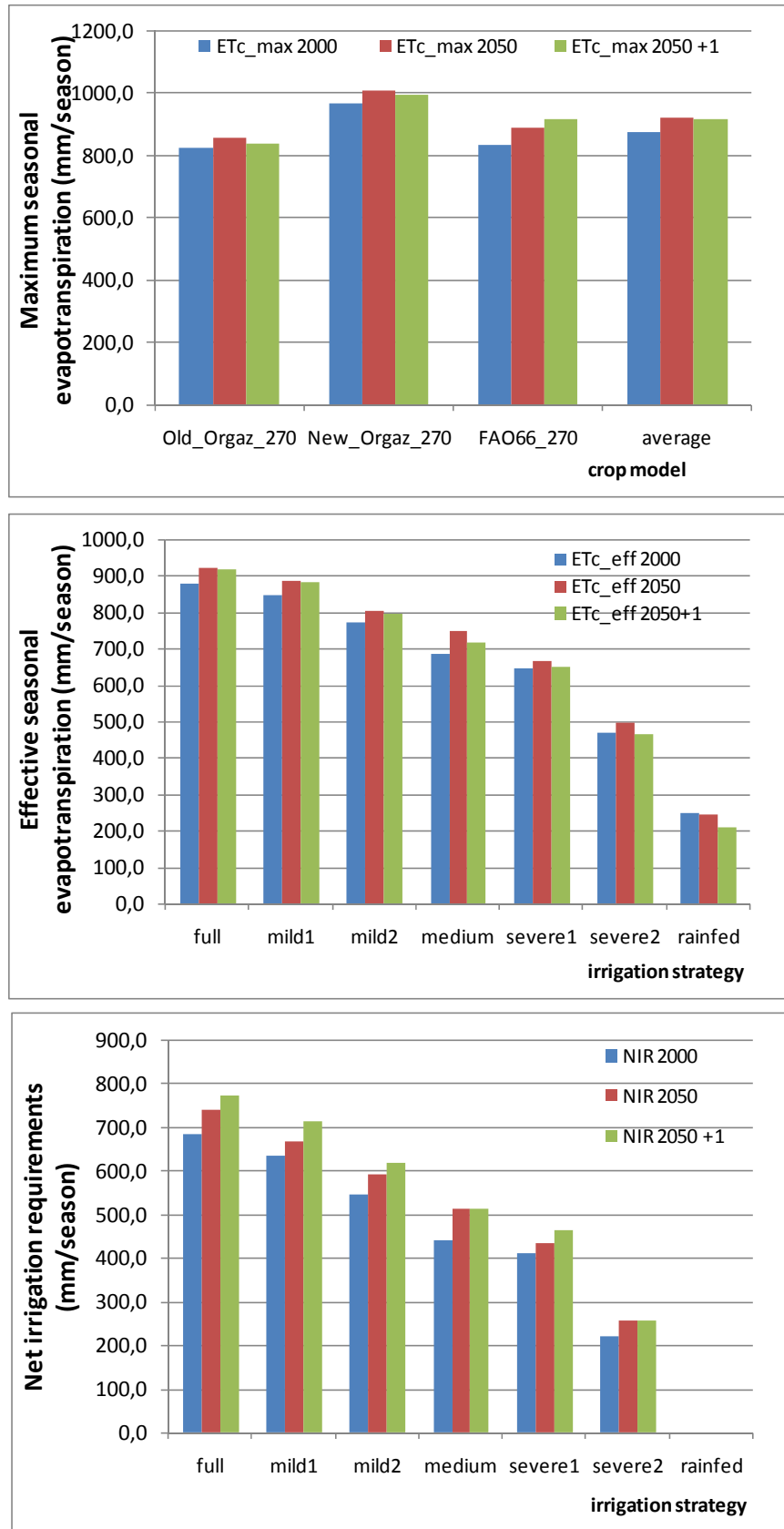


Fig. 55 – Effect of Kc model and irrigation strategies on maximum and effective crop evapotranspiration and net irrigation requirements of olive in Merguellil catchment (Tunisia) under “present”, “future” and “extreme weather” climate conditions.

4.5.3. Yield response to water

The impact of climate change on potential yield, considering the relative effect of selected adaptation strategies (deficit irrigation strategies), as estimated by the two different yield response models of Rao *et al.* (1988) and Moriana *et al.* (2003) (presented in chapter 2.1.3) are summarized in the following tables and graphs.

According to the results of the first model (Rao *et al.*, 1988) (tab. 75-76 and fig.56):

- yield is projected to increase under both “future” (2050) and “extreme weather” (2050+1) scenarios with respect to current conditions (2000), on average respectively from 13.2 to 13.8 (about +4.9%) and to 13.8 t ha⁻¹ (+4.6%), depending on irrigation strategies and Kc model considered, as a consequence of the expected increase of *ETc*;
- a clear linear reduction in potential yield under increasing water stress conditions is predicted;
- under “severe” water stress (thus only supported by supplemental irrigations) values of 4-7 t ha⁻¹ are still predicted;
- in the case of rainfed conditions, very low yield (around 1.3 t ha⁻¹) is predicted.

According to the results of the alternative model (Moriana *et al.*, 2003) (tab. 77-78 and fig.57):

- yield is projected to remain relatively stable under both “future” (2050) and “extreme weather” (2050+1) scenarios with respect to current conditions (2000), but depending on irrigation strategies and Kc model considered;
- as a consequence of the specific shape of the yield response function curve, a relative stability of potential yield is predicted going from full irrigated to medium stressed conditions, and then reducing under severe stress (only supported by supplemental irrigations) where values of 5-9 t ha⁻¹ are still predicted;
- in the case of rainfed conditions, no yield is predicted.

Tab. 75 – Effect of irrigation strategies on the potential yield of olive in Merguellil catchment (Tunisia) under “present”, “future” and “extreme weather” climate conditions.

Irrigation strategy	Yield 2000 (*)	Yield 2050 (*)		Yield 2050 +1 (*)	
	(t/ha)	(t/ha)	(variation vs 2000)	(t/ha)	(variation vs 2000)
full	13.2	13.8	4.9%	13.8	4.6%
mild1	12.4	13.0	4.1%	12.9	3.4%
mild2	10.0	10.4	3.9%	10.2	1.7%
medium	8.8	9.8	12.1%	9.2	4.9%
severe1	7.3	7.5	2.2%	7.2	-1.2%
severe2	4.4	4.7	6.9%	4.2	-3.0%
rainfed	1.3	1.4	1.1%	1.2	-12.5%
(*) assuming wp (2000) =		1.5	(kg/m3)		

Tab. 76 – Effect of different Kc models on the potential yield of olive in Merguellil catchment (Tunisia) under “present” and “future” climate conditions.

Crop model	Yield 2000 (*)	Yield 2050 (*)		Yield 2050 +1 (*)	
	(t/ha)	(t/ha)	(variation vs 2000)	(t/ha)	(variation vs 2000)
Old_Orgaz_270	12.4	12.9	3.9%	12.6	1.6%
New_Orgaz_270	14.5	15.2	4.3%	14.9	2.8%
FAO66_270	12.5	13.4	6.7%	13.8	9.7%
average	13.2	13.8	4.9%	13.8	4.6%
(*) assuming wp (2000) =		1.5	(kg/m3)		

Tab. 77 – Effect of irrigation strategies on the potential yield of olive in Merguellil catchment (Tunisia) (as modelled according to Moriana *et al.* 2003) under “present”, “future” and “extreme weather” climate conditions.

Irrigation strategy	Yield 2000 (**)	Yield 2050 (**)		Yield 2050 +1 (**)	
	(t/ha)	(t/ha)	(variation vs 2000)	(t/ha)	(variation vs 2000)
full	11.5	11.5	0.0%	11.5	0.0%
mild1	11.4	11.5	0.8%	11.5	0.7%
mild2	10.9	11.2	2.3%	11.1	1.8%
medium	9.9	10.7	8.1%	10.3	4.6%
severe1	9.3	9.6	3.8%	9.3	0.9%
severe2	4.9	5.8	17.4%	4.8	-2.4%
rainfed	0.0	0.0		0.0	
(**) according to the model proposed by Moriana <i>et al.</i> (2003)					

Tab. 78 – Effect of different Kc models on the potential yield of olive in Merguellil catchment (Tunisia) (as modelled according to Moriana *et al.* 2003) under “present” and “future” climate.

Crop model	Yield 2000 (**)	Yield 2050 (**)		Yield 2050 (**)	
	(t/ha)	(t/ha)	(variation vs 2000)	(t/ha)	(variation vs 2000)
Old_Orgaz_270	11.3	11.5	1.1%	11.4	0.5%
New_Orgaz_270	11.3	11.1	-2.3%	11.2	-1.4%
FAO66_270	11.4	11.5	1.2%	11.5	1.2%
average	11.5	11.5	0.0%	11.5	0.0%
(**) according to the model proposed by Moriana <i>et al.</i> (2003)					

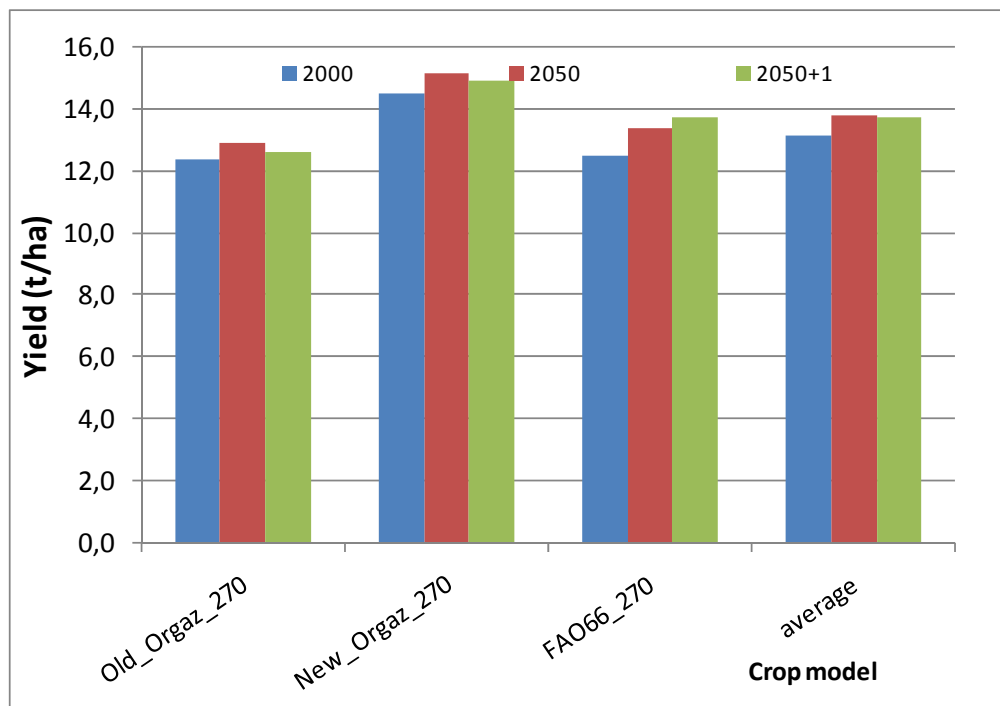
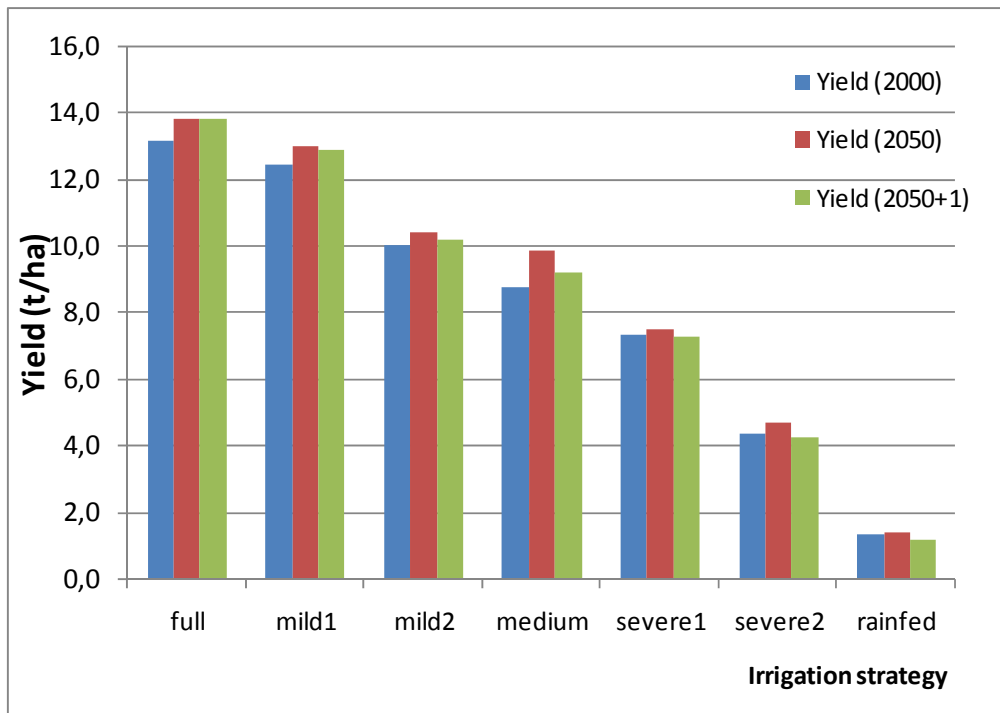


Fig. 56 – Effect of irrigation strategies and Kc model on potential yield of olive in Merguellil catchment (Tunisia) under “present” and “future” climate conditions.

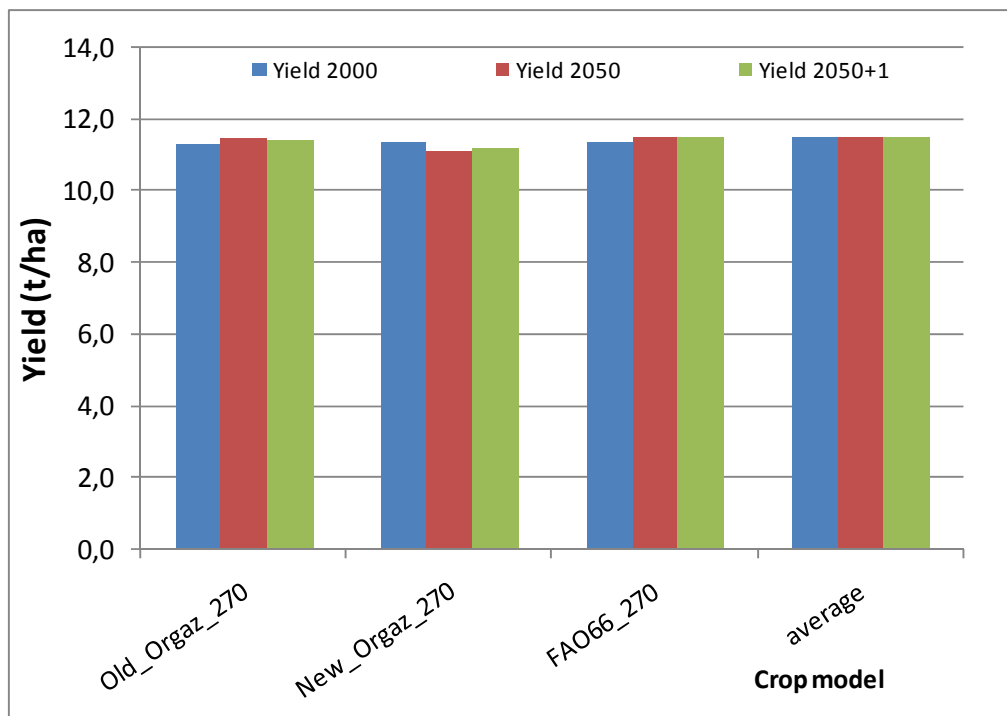
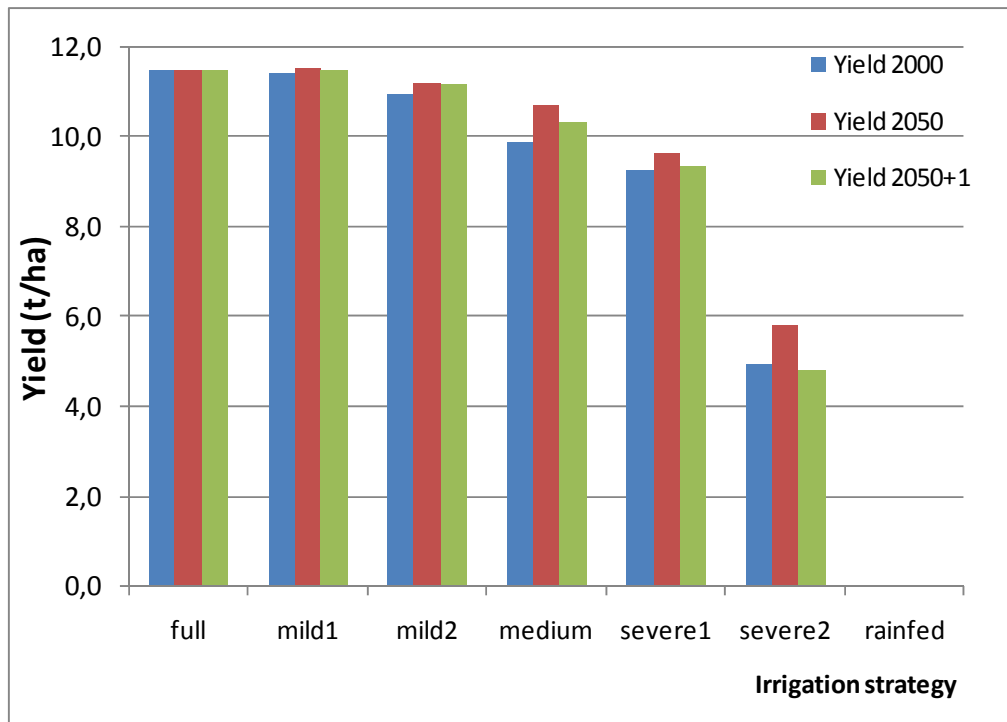


Fig. 57 – Effect of irrigation strategies and Kc model on potential yield of olive in Merguellil catchment (Tunisia) (as modelled according to Moriana *et al.* 2003) under “present” and “future” climate conditions.

5. Case study: Nile Delta, Rosetta (Egypt)

5.1. Climate projections and reference evapotranspiration

With respect to climate projections, as summarized in the following tables and graphs, the following observation are predicted:

- a further reduction of the annual rainfall pattern (-12.9 mm/year), with alternative variations (increasing or decreasing) at monthly scale, with respect to yet very low values;
- a slight increase (+68.8 mm/year) of annual reference evapotranspiration, especially during spring-summer months (with values up to +9 mm/month in June), and with a “peak” of daily evapotranspiration in July (7 mm/day);

Tab. 79 – Monthly and annual average values of predicted rainfall and evapotranspiration under present and future climate conditions in Nile Delta, Rosetta (Egypt).

Month	Rain			ETo		
	2000	2050	var. (mm)	2000	2050	var. (mm)
1	17.6	21.4	3.82	77.2	81.4	4.23
2	3.6	3.0	-0.67	90.4	94.0	3.62
3	11.6	3.0	-8.63	135.1	140.5	5.35
4	2.0	6.7	4.72	159.7	166.9	7.19
5	1.8	1.8	-0.02	192.8	199.8	7.06
6	0.0	0.0	0.00	202.3	211.2	8.96
7	2.5	2.7	0.20	212.1	219.7	7.53
8	3.1	5.7	2.56	194.9	202.3	7.41
9	6.1	4.2	-1.91	156.5	161.6	5.08
10	3.3	12.6	9.33	124.0	128.2	4.29
11	25.7	9.5	-16.16	88.8	93.7	4.94
12	16.8	10.6	-6.19	74.8	78.0	3.14
Total	94.1	81.1	-12.94	1708.6	1777.4	68.81

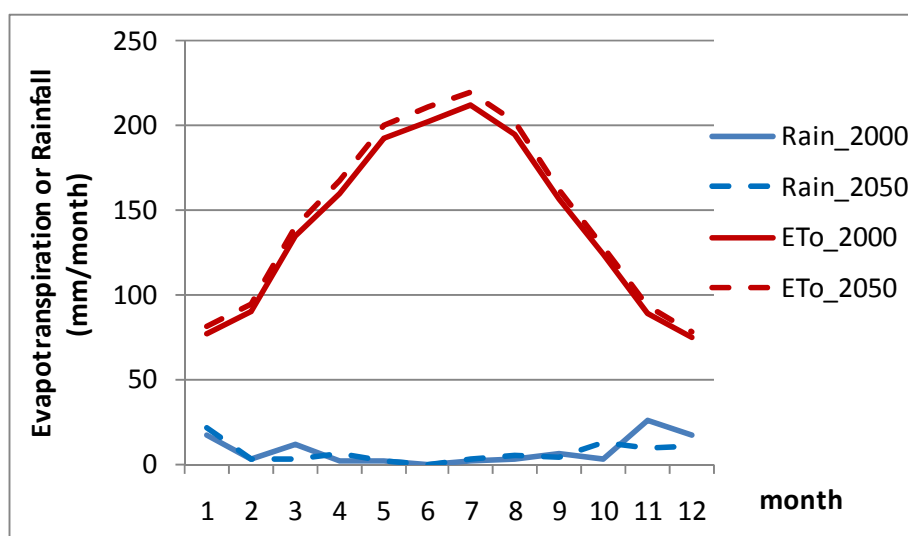


Fig. 58 – Monthly trends of predicted rainfall and evapotranspiration under present and future climate conditions in Nile Delta, Rosetta (Egypt).

- an important increase in annual average maximum, minimum and average air temperatures, up to +1.4°C;
- a relatively uniform increase in monthly average maximum, minimum and average air temperature, with values ranging from +1.3 to 1.6°C/month;
- an increase in the “peak” air temperature during the hotter month of July, with average maximum value projected to reach 33.0°C.

Tab. 80 – Monthly and annual average values and relative variations of predicted maximum, minimum and average air temperature under present and future climate conditions in Nile Delta, Rosetta (Egypt).

Month	Tmax			Tmin			Tmean		
	2000	2050	var. (°C)	2000	2050	var. (°C)	2000	2050	var. (°C)
1	17.6	19.3	1.6	8.9	10.4	1.5	13.3	14.8	1.6
2	19.2	20.7	1.4	9.3	10.7	1.4	14.3	15.7	1.4
3	22.4	23.6	1.2	11.1	12.3	1.2	16.7	17.9	1.2
4	25.1	26.3	1.2	13.1	14.2	1.1	19.1	20.2	1.1
5	27.9	29.2	1.3	15.5	16.7	1.3	21.7	23.0	1.3
6	30.0	31.5	1.5	18.1	19.5	1.4	24.0	25.5	1.5
7	31.6	33.0	1.4	20.1	21.4	1.4	25.8	27.2	1.4
8	31.3	32.9	1.6	20.5	22.0	1.5	25.9	27.4	1.5
9	29.3	30.8	1.5	19.3	20.8	1.6	24.3	25.8	1.5
10	26.6	27.9	1.3	17.2	18.8	1.6	21.9	23.4	1.5
11	22.6	24.0	1.4	14.0	15.5	1.6	18.3	19.8	1.5
12	18.6	20.2	1.6	10.5	12.0	1.6	14.6	16.1	1.6
Average	25.2	26.6	1.4	14.8	16.2	1.4	20.0	21.4	1.4

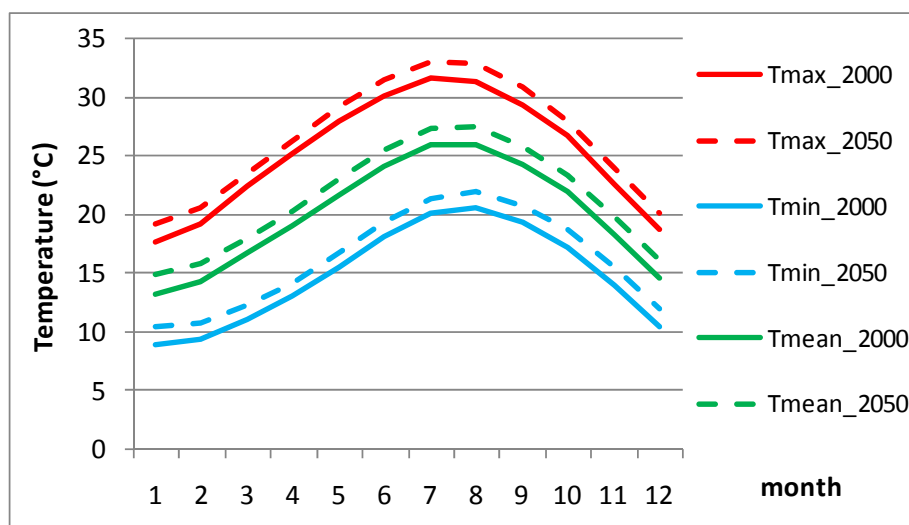


Fig. 59 – Monthly trends of predicted maximum, minimum and mean air temperatures under present and future climate conditions in Nile Delta, Rosetta (Egypt).

5.2. Wheat

5.2.1. Cycle length and crop coefficient curves

The effect of temperature increase (and relative GDD accumulation) on current and projected crop cycle length and corresponding crop coefficient curves is represented in the following graphs, and the following observations have to be highlighted:

- if varietal adaptation is not considered, an important reduction of the total growing cycle is predicted for all planting dates, because of the faster accumulation of the required GGD sum under “future” climate conditions (2050) (fig. 60-61);
- on the contrary, if a late maturing variety will be used, the total crop cycle length (2050 late_var) is projected to remain relatively the same as for the current variety under “present” climate conditions (2000) (fig. 61);
- with respect to the four crop coefficient stages, a relative reduction is predicted in proportion to the corresponding increase in the cumulative GDD (lower during winter, higher during spring-summer months), both in the case of early (November) and late (February) sowing dates (fig. 60).

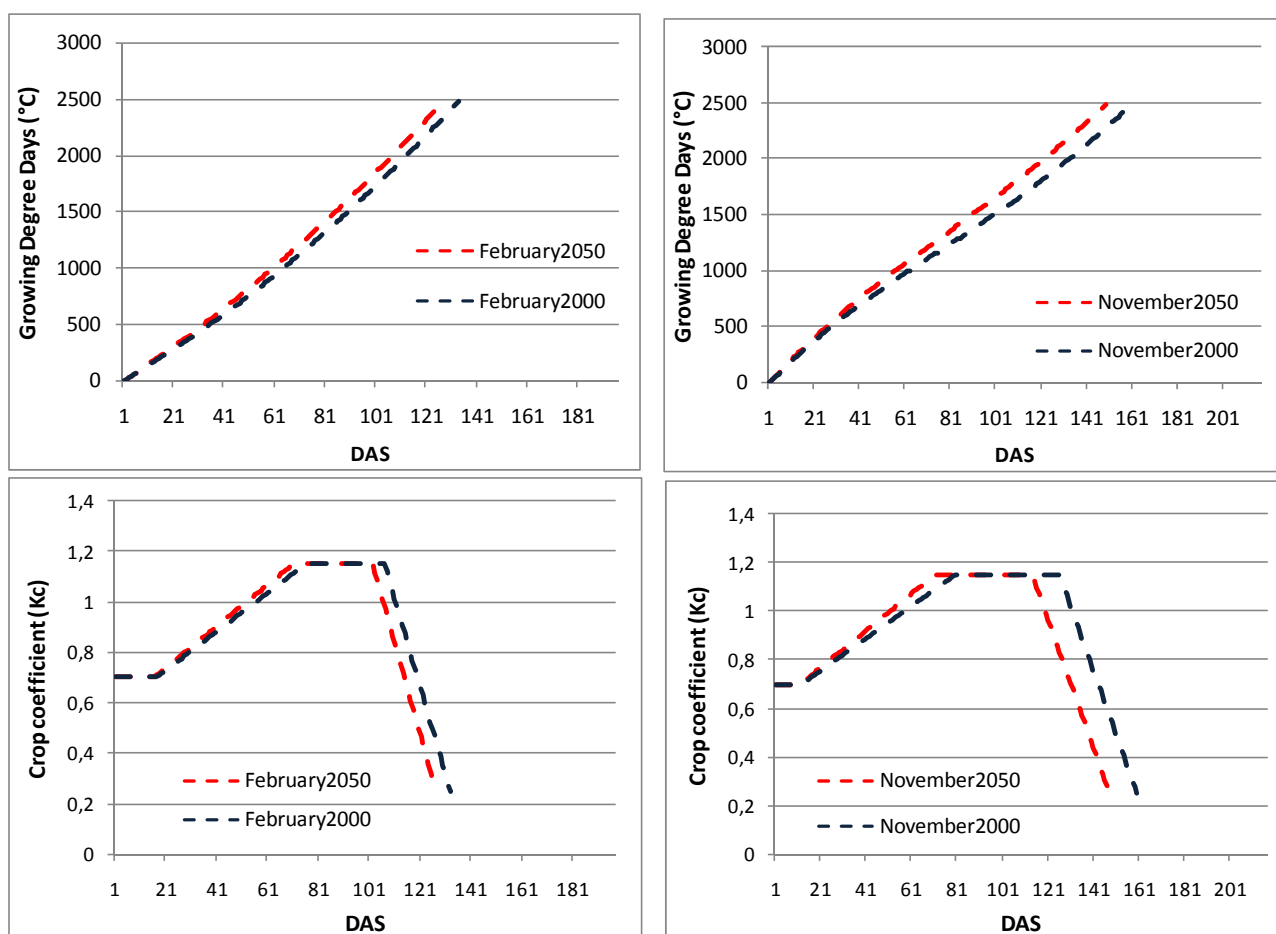


Fig. 60 – Predicted cumulative GDD and corresponding Kc curves for wheat in Nile Delta, Rosetta (Egypt) as affected by different planting dates and climate scenarios.

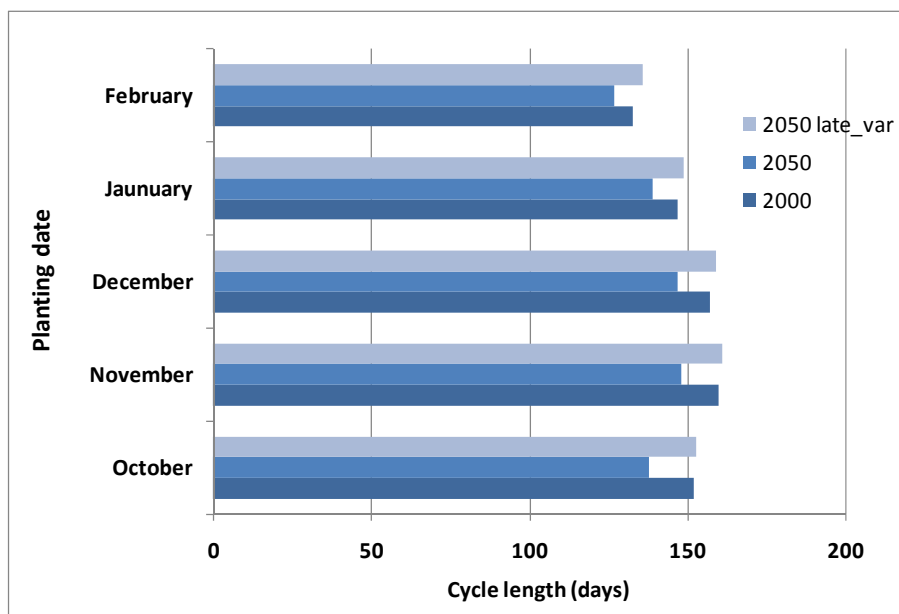


Fig. 61 – Length of total growing cycle of wheat in Nile Delta, Rosetta (Egypt) as affected by planting date, variety selection and climate variations.

5.2.2. Crop evapotranspiration and irrigation requirements

The impact of climate change on maximum and effective crop evapotranspiration as well as on net irrigation requirements, also considering the relative effect of selected adaptation strategies (planting dates, variety selection and deficit irrigation strategies), is summarized in the following tables and graphs. In brief, the following observations are reported:

- maximum seasonal crop evapotranspiration is projected to reduce for the current variety under “future” (2050) scenario as a consequence of the expected shortening of the crop growing cycle, on average of about -5.4% with respect to current conditions (2000) (fig. 63 and tab.81);
- on the contrary, if a late maturing variety (2050 late_var) is selected, maximum evapotranspiration is projected to increase (on average of about +6.3%) for all the planting dates (fig. 63 and tab.81);
- the relative effect of the projected variation of rainfall patterns seems to be slightly relevant for the crop water balance, due to their very low values (fig. and tab.82);
- maximum seasonal crop evapotranspiration is observed always to increase (in absolute terms) for late (February) planting date with respect to earlier (October) ones, because of the shifting of most of the cycle towards the spring-summer season (fig. 63 and tab.82);
- effective seasonal crop evapotranspiration and net irrigation requirements are both highly dependent on the irrigation strategy, progressively reducing going from full irrigation to rainfed conditions (fig. 63 and tab.83-84);
- as for ET_{c_max} , also the ET_{c_eff} and NIR are projected to decrease in 2050 if the current variety is used, while to remain relatively stable if a late maturing variety is selected, depending on the irrigation strategy considered (fig. 63 and tab.83-84);

Tab. 81 – Effect of planting date and variety selection on the maximum crop evapotranspiration of wheat in Nile Delta, Rosetta (Egypt) under “present” and “future” climate conditions.

Planting date	ETc_max 2000	ETc_max 2050		ETc_max 2050 late_var	
	[mm/season]	[mm/season]	(variation vs 2000)	[mm/season]	(variation vs 2000)
october	399.2	374.7	-6.1%	420.5	5.3%
november	453.7	414.6	-8.6%	477.2	5.2%
december	519.4	485.5	-6.5%	551.0	6.1%
january	549.4	524.2	-4.6%	584.2	6.4%
february	605.4	592.5	-2.1%	652.5	7.8%
average	505.4	478.3	-5.4%	537.1	6.3%

Tab. 82 – Effect of planting date and variety selection on the effective rainfall pattern during crop cycle of wheat in Nile Delta, Rosetta (Egypt) under “present” and “future” climate conditions.

Planting date	Rain_eff 2000	Rain_eff 2050		Rain_eff 2050 late_var	
	[mm/season]	[mm/season]	(variation vs 2000)	[mm/season]	(variation vs 2000)
october	53.8	43.3	-19.6%	45.6	-15.2%
november	56.5	37.9	-32.9%	40.0	-29.3%
december	41.3	34.4	-16.6%	35.7	-13.5%
january	21.8	18.0	-17.5%	19.4	-10.7%
february	15.3	11.6	-24.1%	11.6	-24.1%
average	37.7	29.0	-23.0%	30.5	-19.2%

Tab. 83 – Effect of irrigation strategies and variety selection on the effective evapotranspiration of wheat in Nile Delta, Rosetta (Egypt) under “present” and “future” climate conditions.

Irrigation strategy	ETc_eff 2000	ETc_eff 2050		ETc_eff 2050 late_var	
	[mm/season]	[mm/season]	(variation vs 2000)	[mm/season]	(variation vs 2000)
full	505.4	478.3	-5.4%	537.1	6.3%
mild1	487.9	461.4	-5.4%	515.5	5.7%
mild2	456.0	433.8	-4.9%	481.3	5.5%
medium	425.8	406.8	-4.5%	450.9	5.9%
severe1	381.7	361.4	-5.3%	396.7	3.9%
severe2	296.8	282.8	-4.7%	305.7	3.0%
rainfed	164.7	154.8	-6.0%	156.8	-4.8%

Tab. 84 – Effect of irrigation strategies and variety selection on the net irrigation requirements of wheat in Nile Delta, Rosetta (Egypt) under “present” and “future” climate conditions.

Irrigation strategy	NIR 2000	NIR 2050		NIR 2050 late_var	
	[mm/season]	[mm/season]	(variation vs 2000)	[mm/season]	(variation vs 2000)
full	434.2	413.1	-4.9%	462.2	6.5%
mild1	385.4	376.8	-2.3%	423.2	9.8%
mild2	347.4	330.5	-4.9%	369.8	6.5%
medium	315.9	292.8	-7.3%	341.6	8.1%
severe1	250.5	244.9	-2.3%	275.1	9.8%
severe2	158.0	146.4	-7.3%	170.8	8.1%
rainfed	0.0	0.0		0.0	

- by plotting together the values of seasonal ETc_{eff} and NIR (obtained under different irrigation strategies and variety) for different climate scenarios, there is a clear prediction of their reduction (respectively of about -4.9% and -4.7%, on average) while, by considering a late maturing variety, an increase of both (respectively of about +5.2% and +7.3%, on average) (fig.62);
- the cumulative curves of ETc_{max} in 2050 (versus 2000) show always (also under different planting dates) a slight increase towards higher values, thus representing the relative increase in the daily crop water requirements, although with a decrease in the cumulative final value (depending on the anticipated ending of the cycle) (fig.64).

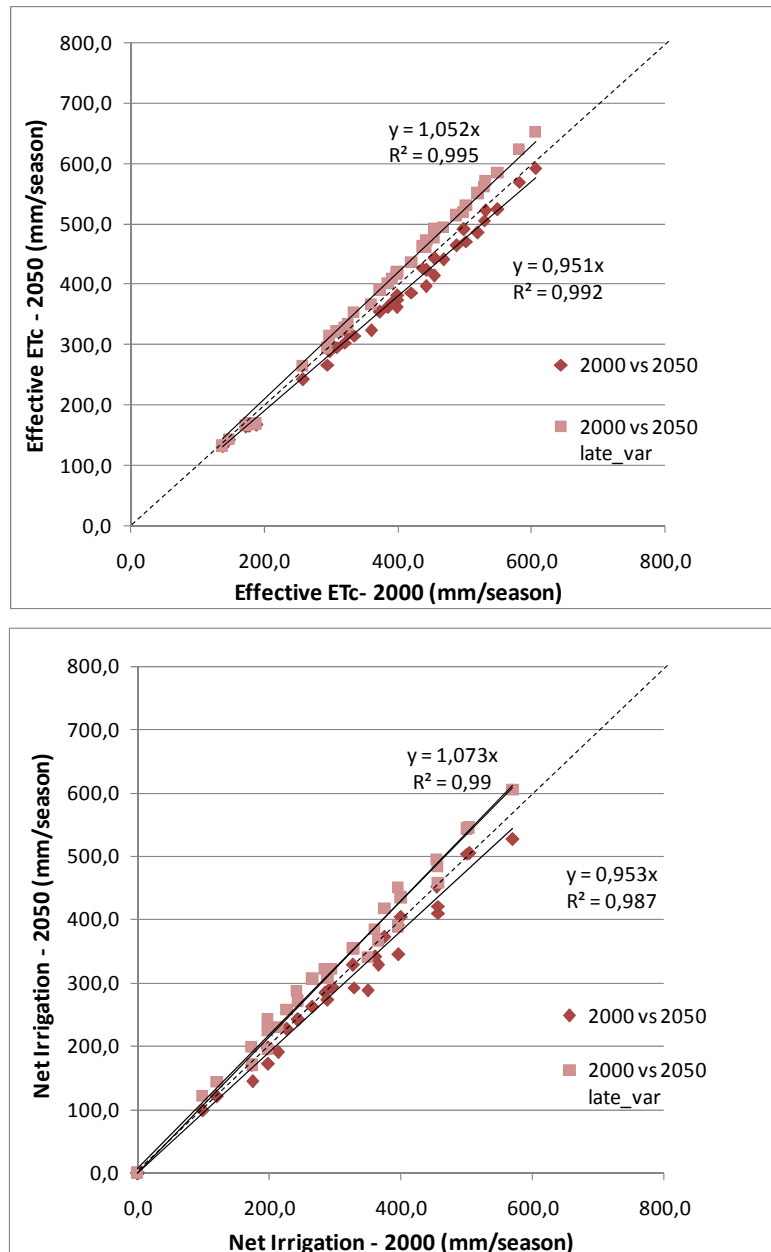


Fig. 62 – Scatter-plot of seasonal crop evapotranspiration and net irrigation requirements of as affected by different variety selection for wheat in Nile Delta, Rosetta (Egypt) under “present” and “future” climate conditions.

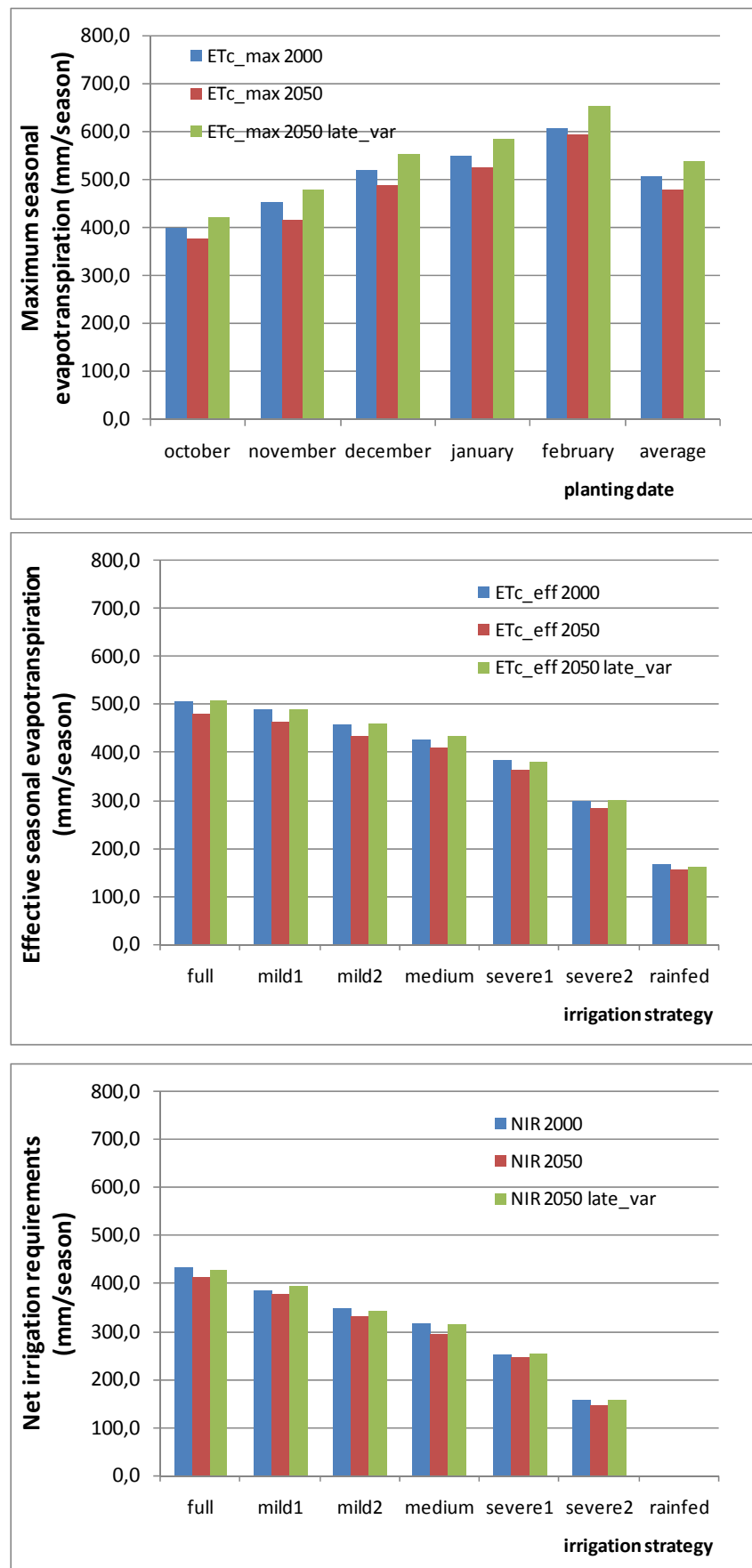


Fig. 63 – Effect of planting date, irrigation strategies and variety selection on maximum and effective crop evapotranspiration and net irrigation requirements of wheat in Nile Delta, Rosetta (Egypt) under “present” and “future” climate conditions.

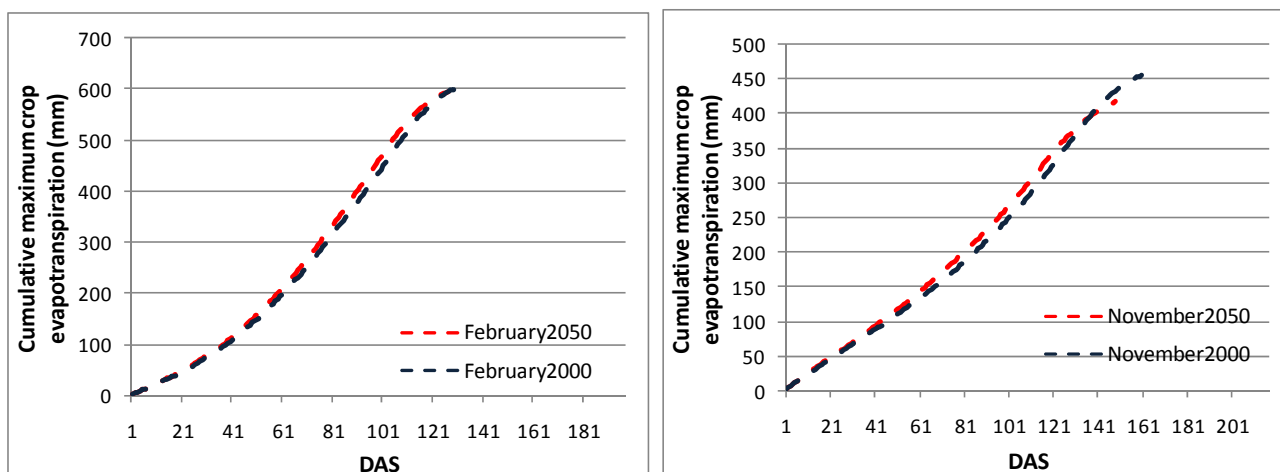


Fig. 64 – Cumulative curves of maximum crop evapotranspiration as affected by different planting date for wheat in Nile Delta, Rosetta (Egypt) under “present” and “future” climate conditions.

5.2.3. Crop evapotranspiration under extreme weather conditions

If a simulated future “extreme weather” climate condition (2050+1) is considered (created by adding +1°C to daily temperature of 2050 climate scenario), the following observations on crop cycle length are reported (fig.65):

- with current variety, a further important reduction of the total growing cycle is predicted for quite all planting dates with respect to 2000 and 2050 scenario, because of the further faster accumulation of the required GDD sum;
- if a late maturing variety is considered, the total crop cycle length (2050+1 late_var) is partly recovered with respect to present (2000) scenario only in the case of late planting dates (January, February), while it is significantly shortened in all other cases with respect to 2050 late_var and 2000 scenarios.

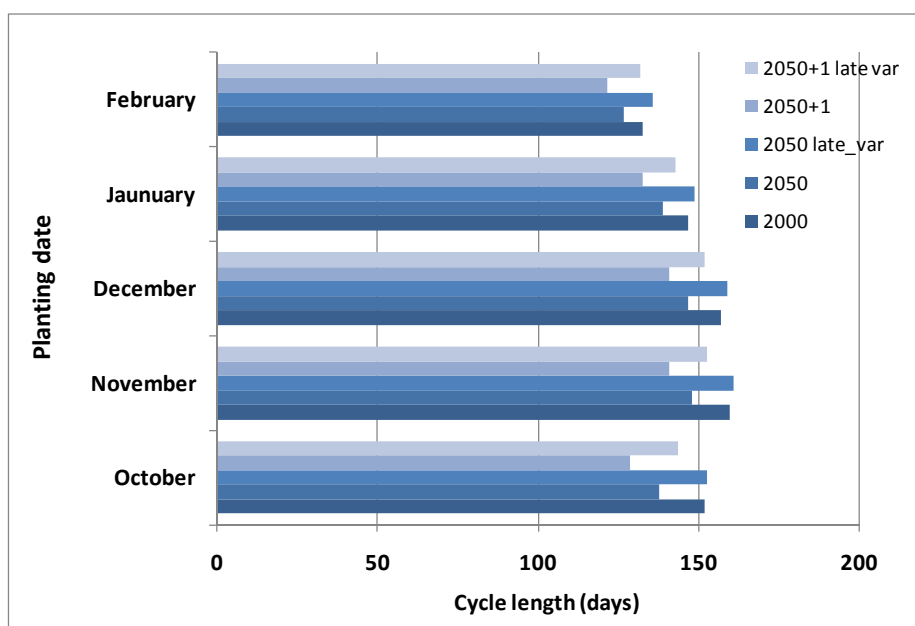


Fig. 65 – Length of total growing cycle of wheat in Nile Delta, Rosetta (Egypt) as affected by planting date and variety selection under “present (2000)”, “future (2050)” and “future extreme weather (2050+1)” climate conditions.

The impact of future “extreme weather” conditions (2050+1) on maximum and effective crop evapotranspiration as well as on net irrigation requirements, also considering the relative effect of selected adaptation strategies (planting dates, variety selection and deficit irrigation strategies), is summarized in the following tables and graphs. In brief, the following observations are reported:

- *ETc_max* is projected to reduce for the current variety under future “extreme weather” (2050+1) scenario as a consequence of the expected further shortening of the crop growing cycle, on average of about -8.8% with respect to present conditions (2000); on the contrary, if a late maturing variety (2050+1 late_var) is selected, *ETc_max* is projected to increase (+2.7% on average) (tab.85);
- *ETc_max* is observed always to increase (in absolute terms) for late (February) planting date with respect to earlier (October) ones, because of the shifting of most of the cycle towards the hotter spring-summer season (fig. 66 and tab.85);
- the relative effect of the projected variation of rainfall patterns (higher than -40%) seems to be not relevant for the crop water balance, because of the reduction very low values considered (tab.86);
- *ETc_eff* is projected to decrease under 2050+1 scenario if the current variety is used; if a late maturing variety is selected (tab.87), it is projected to decrease (under rainfed and severe conditions) or to increase (under better irrigated conditions), always with respect to 2000 baseline scenario;
- on the other side, *NIR* is projected to decrease under 2050+1 scenario if the current variety is used, or again to increase significantly if a late maturing variety is selected (tab.88), always with respect to 2000 baseline scenario;
- *ETc_eff* and *NIR* are both highly dependent on the irrigation strategy, progressively reducing going from full irrigation to rainfed conditions, under all climate scenarios (fig.66);
- by plotting together the values of seasonal *ETc_eff* and *NIR* for 2000 versus 2050+1 climate scenarios, there is a clear prediction of *ETc_eff* and *NIR* reduction with current variety (respectively of about -10.1% and -6.1%, on average), or of their increase if a late maturing variety is considered (respectively of about +0.3% and +5.7%, on average) (fig.67).

Tab. 85 – Effect of planting date and variety selection on the maximum crop evapotranspiration of wheat in Nile Delta, Rosetta (Egypt) under “present”, “future” and “future extreme weather” climate conditions.

Planting date	ETc_max 2000	ETc_max 2050		ETc_max 2050 late_var		ETc_max 2050+1		ETc_max 2050+1 late_var	
	(mm)	(mm)	var.% (2000)	(mm)	var.% (2000)	(mm)	var.% (2000)	(mm)	var.% (2000)
october	399.2	374.7	-6.1%	420.5	5.3%	364.0	-8.8%	406.3	1.8%
november	453.7	414.6	-8.6%	477.2	5.2%	396.3	-12.6%	454.2	0.1%
december	519.4	485.5	-6.5%	551.0	6.1%	467.0	-10.1%	528.7	1.8%
january	549.4	524.2	-4.6%	584.2	6.4%	502.0	-8.6%	565.1	2.9%
february	605.4	592.5	-2.1%	652.5	7.8%	576.1	-4.8%	641.9	6.0%
average	505.4	478.3	-5.4%	537.1	6.3%	461.1	-8.8%	519.3	2.7%

Tab. 86 – Effect of planting date and variety selection on the effective rainfall pattern during crop cycle of wheat in Nile Delta, Rosetta (Egypt) under “present”, “future” and “future extreme weather” climate conditions.

Planting date	Rain_eff 2000	Rain_eff 2050		Rain_eff 2050 late_var		Rain_eff 2050+1		Rain_eff 2050+1 late_var	
	(mm)	[mm/season]	var.% (2000)	(mm)	var.% (2000)	(mm)	var.% (2000)	(mm)	var.% (2000)
october	53.8	43.3	-19.6%	45.6	-15.2%	30.3	-43.7%	32.0	-40.6%
november	56.5	37.9	-32.9%	40.0	-29.3%	26.6	-53.0%	26.6	-53.0%
december	41.3	34.4	-16.6%	35.7	-13.5%	24.1	-41.6%	25.0	-39.4%
january	21.8	18.0	-17.5%	19.4	-10.7%	12.6	-42.2%	12.6	-42.2%
february	15.3	11.6	-24.1%	11.6	-24.1%	8.1	-46.8%	8.1	-46.8%
average	37.7	29.0	-23.0%	30.5	-19.2%	20.3	-46.1%	20.8	-44.8%

Tab. 87 – Effect of irrigation strategies and variety selection on the effective crop evapotranspiration of wheat in Nile Delta, Rosetta (Egypt) under “present”, “future” and “future extreme weather” climate conditions.

Irrigation strategy	ETc_eff 2000	ETc_eff 2050		ETc_eff 2050 late_var		ETc_eff 2050+1		ETc_eff 2050+1 late_var	
	(mm)	(mm)	var.% (2000)	(mm)	var.% (2000)	(mm)	var.% (2000)	(mm)	var.% (2000)
full	505.4	478.3	-5.4%	537.1	6.3%	461.1	-8.8%	519.3	2.7%
mild1	487.9	461.4	-5.4%	515.5	5.7%	440.7	-9.7%	496.6	1.8%
mild2	456.0	433.8	-4.9%	481.3	5.5%	413.8	-9.3%	460.0	0.9%
medium	425.8	406.8	-4.5%	450.9	5.9%	378.9	-11.0%	425.2	-0.1%
severe1	381.7	361.4	-5.3%	396.7	3.9%	338.9	-11.2%	375.5	-1.6%
severe2	296.8	282.8	-4.7%	305.7	3.0%	258.0	-13.1%	281.8	-5.1%
rainfed	164.7	154.8	-6.0%	156.8	-4.8%	133.7	-18.8%	135.2	-17.9%

Tab. 88 – Effect of irrigation strategies and variety selection on the net irrigation requirements of wheat in Nile Delta, Rosetta (Egypt) under “present”, “future” and “future extreme weather” climate conditions.

Irrigation strategy	NIR 2000	NIR 2050		NIR 2050 late_var		NIR 2050+1		NIR 2050+1 late_var	
	(mm)	(mm)	var.% (2000)	(mm)	var.% (2000)	(mm)	var.% (2000)	(mm)	var.% (2000)
full	434.2	413.1	-4.9%	462.2	6.5%	407.1	-6.2%	460.5	6.1%
mild1	385.4	376.8	-2.3%	423.2	9.8%	367.5	-4.6%	409.7	6.3%
mild2	347.4	330.5	-4.9%	369.8	6.5%	325.7	-6.2%	368.4	6.1%
medium	315.9	292.8	-7.3%	341.6	8.1%	295.9	-6.3%	334.7	5.9%
severe1	250.5	244.9	-2.3%	275.1	9.8%	238.9	-4.6%	266.3	6.3%
severe2	158.0	146.4	-7.3%	170.8	8.1%	148.0	-6.3%	167.3	5.9%
rainfed	0.0	0.0		0.0		0.0		0.0	

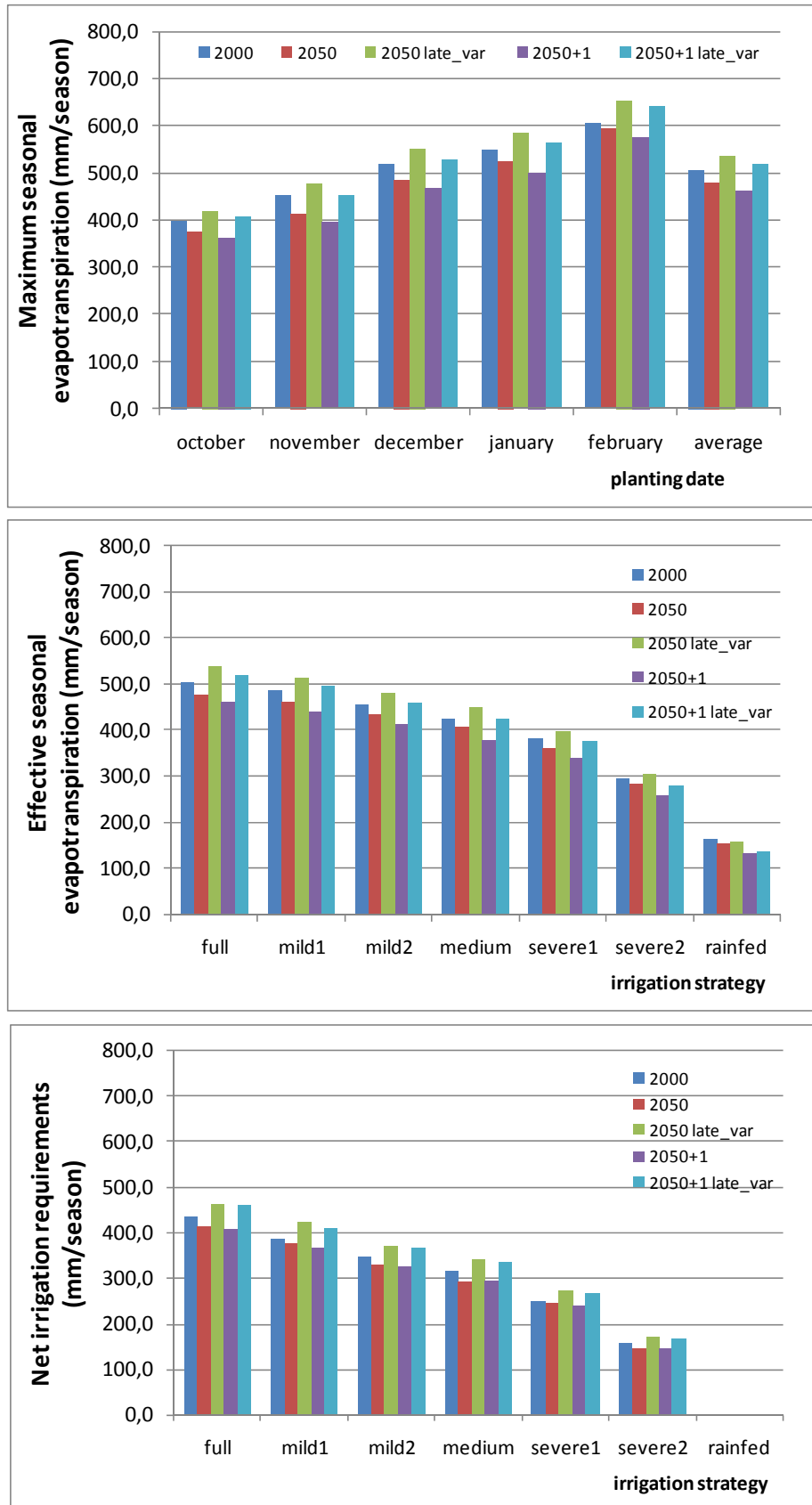


Fig. 66 – Effect of planting date, irrigation strategies and variety selection on maximum and effective crop evapotranspiration and net irrigation requirements of wheat in Nile Delta, Rosetta (Egypt) under “present” and “future” and “extreme weather (2050+1)” climate conditions.

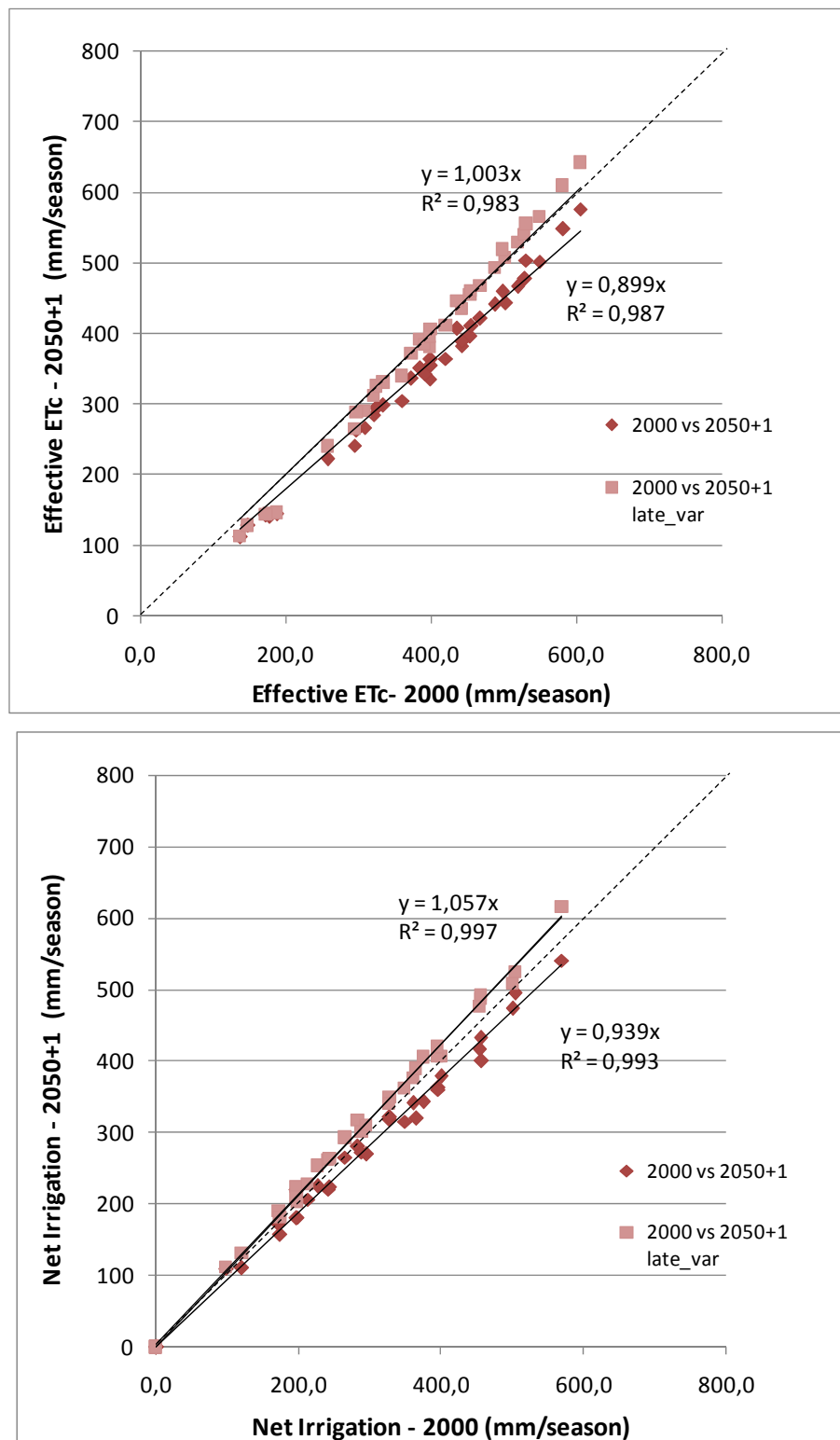


Fig. 67 – Scatter-plot of seasonal crop evapotranspiration and net irrigation requirements of as affected by different variety selection for wheat in Nile Delta, Rosetta (Egypt) under “present (2000)” and “future extreme weather (2050+1)” climate conditions.

5.2.4. Yield response to water

The impact of “future” climate projections (2050) and “extreme weather” (2050+1) on potential yield, also considering the relative effect of selected adaptation strategies (planting dates, variety selection and deficit irrigation strategies), is summarized in the following tables and graphs. In brief, the following observations are reported:

- potential yield is projected to reduce under “future” scenario (2050) with respect to current conditions (2000), on average from 5.1 to 4.8 t ha⁻¹ (about -5.4%), depending on irrigation strategies (tab. 89 and fig.68) and planting dates (tab. 90 and fig) as a consequence of the expected shortening of the crop growing cycle;
- on the contrary, if the expected fertilizing effect due to an increase in atmospheric CO₂ concentration will occur, yield is projected to increase in quite all conditions (2050 wp_adj), up to an average of 5.7 t ha⁻¹ (+13.6%), and thus to overcome the effect of the shortening of the crop cycle (fig. 68 and tab. 89-90);
- on the other side, if a late maturing variety (2050 late_var) is selected, yield is projected to increase up to an average of 5.4 t ha⁻¹ (+6.3%), especially under fully irrigation (fig. 68 and tab.89-90);
- if “extreme weather” conditions (2050+1) are considered, the average expected yield reduction (down to 4.6 t ha⁻¹, -8.8%) is greater than in 2050 scenario, but also in this case it could be completely recovered because of the CO₂ fertilizing effect or the late-variety selection, respectively to 5.5 t ha⁻¹ (+9.5%) and 5.2 t ha⁻¹ (+2.7%);
- with respect to irrigation strategies, there is a clear reduction in potential yield under increasing water stress conditions (fig.68), but still under “severe” water stress (thus only supported by supplemental irrigations) values up to 2.5-3.5 t ha⁻¹ are expected, while under rainfed conditions, an average yield of 1-1.5 t ha⁻¹ is still predicted in all climate conditions;
- yield is observed always to increase (in absolute terms) for late (February) planting date with respect to earlier (October) ones (fig.68), but a corresponding increase in crop water requirements is clearly projected (as it has been highlighted in the previous paragraph).

Tab. 89 – Effect of irrigation strategies, variety selection and atmospheric CO₂ increase on the potential yield of wheat in Nile Delta, Rosetta (Egypt) under “present”, “future” and “extreme weather” climate conditions.

Irrigation strategy	Yield 2000 (*)	Yield 2050 (*)		Yield 2050 wp_adj (**)		Yield 2050 late_var (*)		Yield 2050+1 (*)		Yield 2050+1 wp_adj (**)		Yield 2050+1 late_var (*)	
	(t/ha)	(t/ha)	var.% (2000)	(t/ha)	var.% (2000)	(t/ha)	var.% (2000)	(t/ha)	var.% (2000)	(t/ha)	var.% (2000)	(t/ha)	var.% (2000)
full	5.1	4.8	-5.4%	5.7	13.6%	5.4	6.3%	4.6	-8.8%	5.5	9.5%	5.2	2.7%
mild1	4.8	4.5	-5.6%	5.5	13.3%	5.1	5.3%	4.3	-10.0%	5.2	8.0%	4.9	1.3%
mild2	4.3	4.2	-4.4%	5.0	14.7%	4.6	5.3%	3.9	-9.4%	4.7	8.7%	4.3	0.1%
medium	4.0	3.8	-4.4%	4.6	14.8%	4.2	5.7%	3.5	-11.6%	4.3	6.1%	4.0	-1.3%
severe1	3.4	3.2	-5.5%	3.9	13.4%	3.5	3.2%	3.0	-11.9%	3.6	5.7%	3.3	-2.9%
severe2	2.5	2.4	-4.6%	2.9	14.5%	2.6	3.2%	2.2	-13.2%	2.6	4.2%	2.4	-5.3%
rainfed	1.4	1.3	-5.8%	1.6	13.0%	1.4	-1.7%	1.1	-16.7%	1.4	0.0%	1.2	-12.1%
(*) assuming wp (2000) = 1 (kg/m ³)													
(**) assuming wp (2050)= wp(2000)*1.2= 1.2 (kg/m ³)													

Tab. 90 – Effect of planting date, variety selection and atmospheric CO₂ increase on the potential yield of wheat in Nile Delta, Rosetta (Egypt) under “present”, “future” and “extreme weather” climate conditions.

Irrigation strategy	Yield 2000 (*)	Yield 2050 (*)		Yield 2050 wp_adj (**)		Yield 2050 late_var (*)		Yield 2050+1 (*)		Yield 2050+1 wp_adj (**)		Yield 2050+1 late_var (*)	
	(t/ha)	(t/ha)	var.% (2000)	(t/ha)	var.% (2000)	(t/ha)	var.% (2000)	(t/ha)	var.% (2000)	(t/ha)	var.% (2000)	(t/ha)	var.% (2000)
october	4.0	3.7	-6.1%	4.5	12.6%	4.2	5.3%	3.6	-8.8%	4.4	9.4%	4.1	1.8%
november	4.5	4.1	-8.6%	5.0	9.6%	4.8	5.2%	4.0	-12.6%	4.8	4.8%	4.5	0.1%
december	5.2	4.9	-6.5%	5.8	12.2%	5.5	6.1%	4.7	-10.1%	5.6	7.9%	5.3	1.8%
january	5.5	5.2	-4.6%	6.3	14.5%	5.8	6.4%	5.0	-8.6%	6.0	9.6%	5.7	2.9%
february	6.1	5.9	-2.1%	7.1	17.4%	6.5	7.8%	5.8	-4.8%	6.9	14.2%	6.4	6.0%
average	5.1	4.8	-5.4%	5.7	13.6%	5.4	6.3%	4.6	-8.8%	5.5	9.5%	5.2	2.7%
(*) assuming wp (2000) = 1 (kg/m ³)													
(**) assuming wp (2050)= wp(2000)*1.2= 1.2 (kg/m ³)													

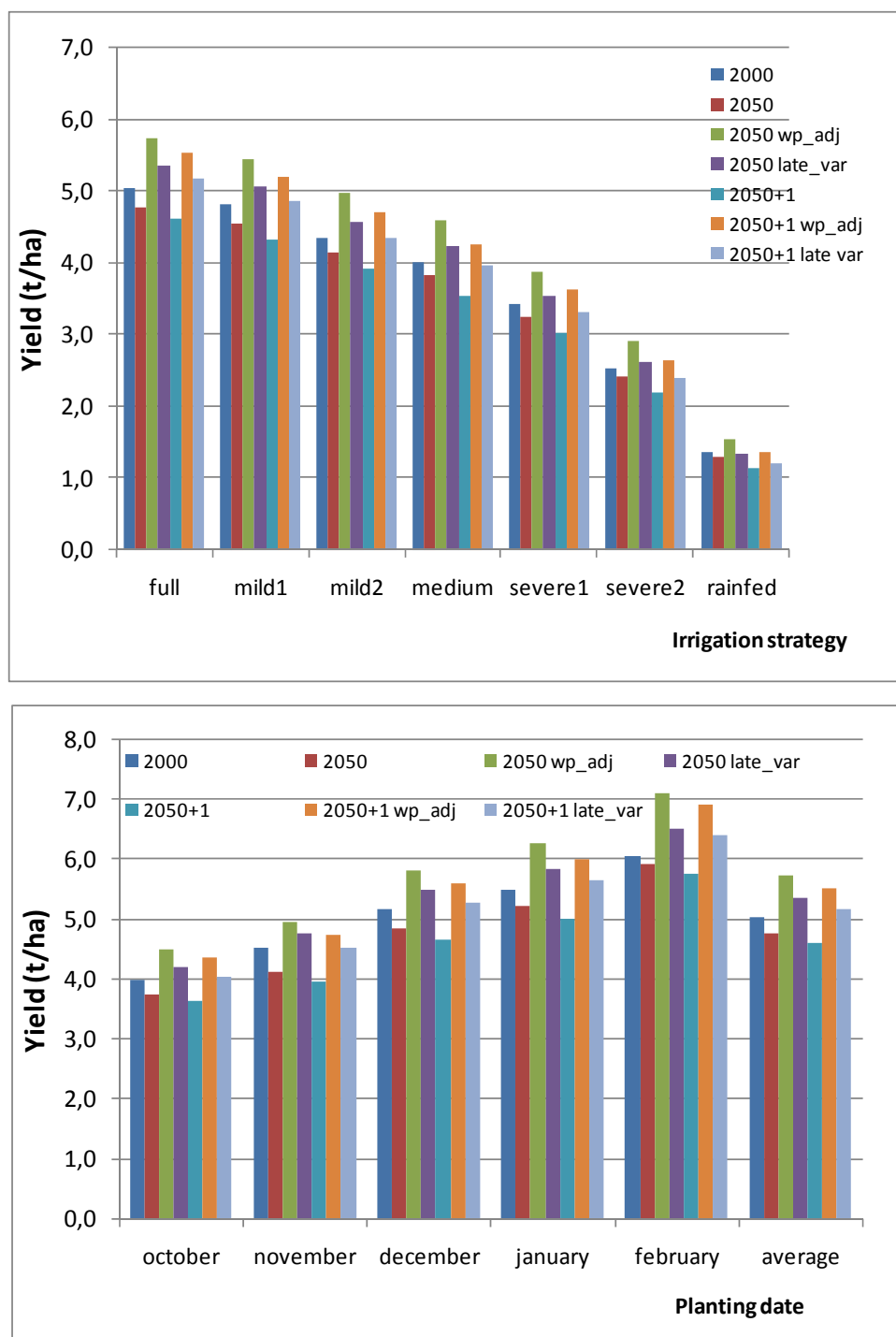


Fig. 68 – Effect of planting date, irrigation strategies, variety selection and atmospheric CO₂ increase on potential yield of wheat in Nile Delta, Rosetta (Egypt) under “present”, “future” and “extreme weather (2050+1)” climate conditions.

5.3. Tomato

5.3.1. Cycle length and crop coefficient curves

The effect of temperature increase (and relative GDD accumulation) on current and projected crop cycle length and corresponding crop coefficient curves is represented in the following graphs, and the following observations have to be highlighted:

- if varietal adaptation is not considered, an important reduction of the total growing cycle is predicted for all planting dates, because of the faster accumulation of the required GGD sum under “future” climate conditions (2050) (fig.69-70);
- if a late maturing variety will be used, the total crop cycle length (2050 late_var) is projected to remain relatively the same as for the current variety under “present” climate conditions (2000), especially for late planting dates (fig.70);
- with respect to the four crop coefficient stages, a relative reduction is predicted in proportion to the corresponding increase in the cumulative GDD (lower during winter, higher during spring-summer months), but with a greater effect in the case of early (February) rather than late (April) planting dates (fig.69).

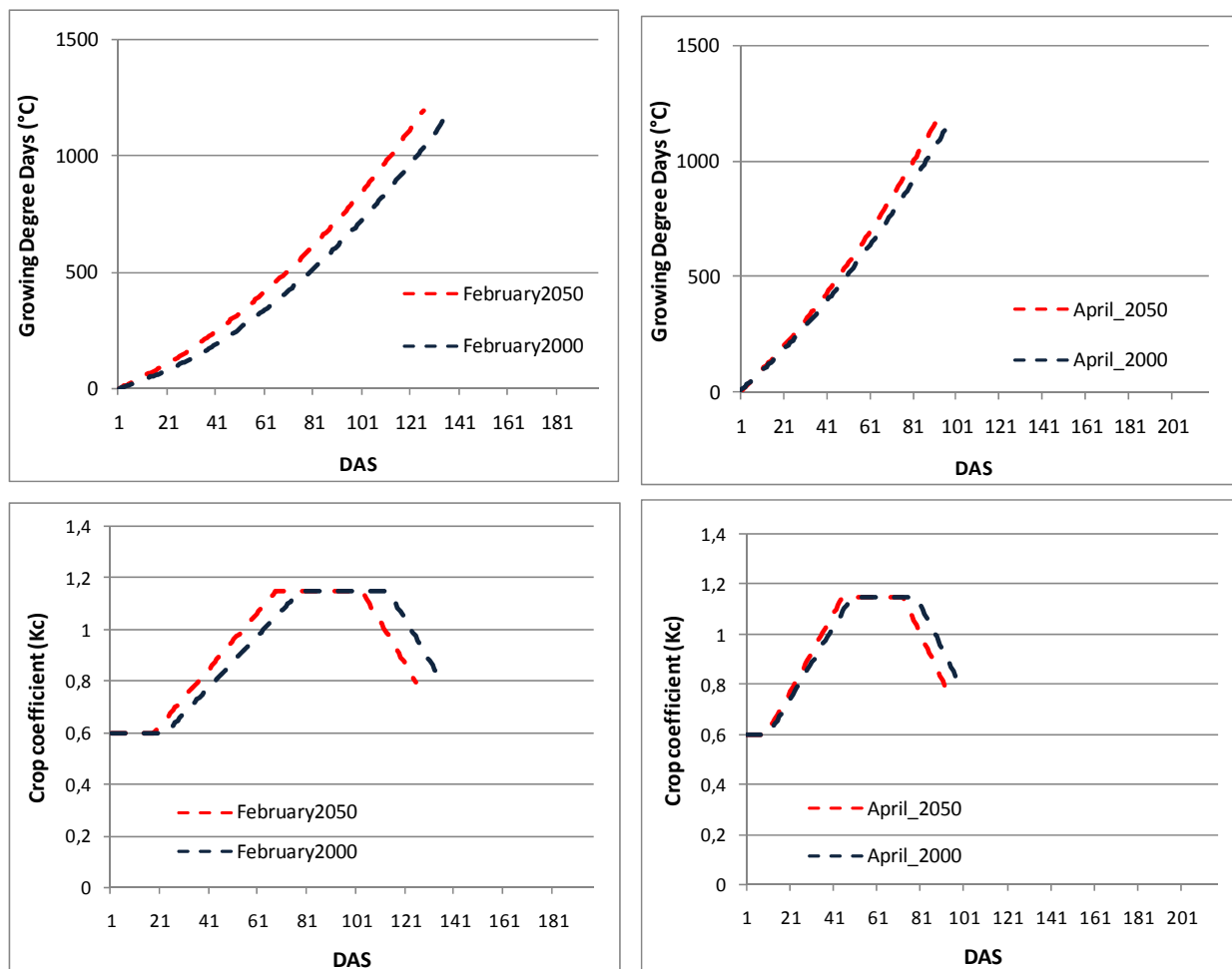


Fig. 69 – Predicted cumulative GDD and corresponding Kc curves for tomato in Nile Delta, Rosetta (Egypt) as affected by different planting dates and climate scenarios.

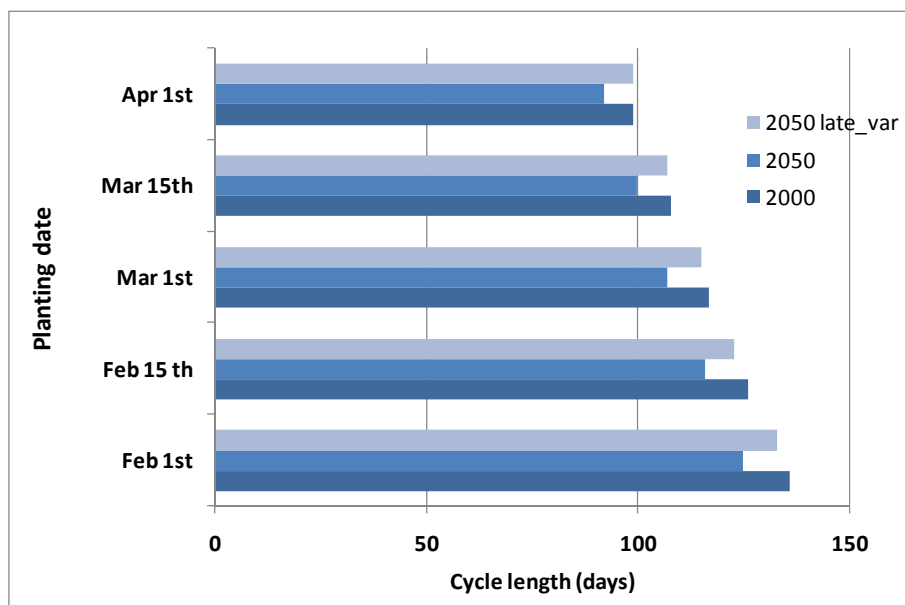


Fig. 70 – Length of total growing cycle of tomato in Nile Delta, Rosetta (Egypt) as affected by planting date, variety selection and climate variations.

5.3.2. Crop evapotranspiration and irrigation requirements

The impact of climate change on maximum and effective crop evapotranspiration as well as on net irrigation requirements, also considering the relative effect of selected adaptation strategies (planting dates, variety selection and deficit irrigation strategies), is summarized in the following tables and graphs. In brief, the following observations are reported:

- maximum seasonal crop evapotranspiration is projected to reduce for the current variety under “future” (2050) scenario as a consequence of the expected shortening of the crop growing cycle, on average of about -5.4% with respect to current conditions (2000) (fig. 72 and tab.91);
- on the contrary, if a late maturing variety (2050 late_var) is selected, maximum evapotranspiration is projected to increase for all the planting dates (on average of about +3.2%) (fig. 72 and tab.91);
- the relative effect of the projected decrease of rainfall patterns seems to be less relevant for the crop water balance, because of their very low values (tab.92);
- maximum seasonal crop evapotranspiration is observed always to decrease slightly (in absolute terms) for late (April) planting date with respect to earlier (February) ones, because of the shifting of the cycle towards the higher summer temperatures and the corresponding reduction in the total length (fig. 72 and tab.91);
- effective seasonal crop evapotranspiration and net irrigation requirements are both highly dependent on the irrigation strategy, progressively reducing going from full irrigation to rainfed conditions (fig. 72 and tab.93-94);
- as for ETc_{max} , also the ETc_{eff} and NIR are projected to decrease in 2050 if the current variety is used; on the other side, if a late maturing variety is selected, NIR and ETc_{eff} are always projected to increase (fig. 72 and tab.93-94);

Tab. 91 – Effect of planting date and variety selection on the maximum crop evapotranspiration of tomato in Nile Delta, Rosetta (Egypt) under “present” and “future” climate conditions.

Planting date	ETc_max 2000	ETc_max 2050		ETc_max 2050 late_var	
	[mm/season]	[mm/season]	(variation vs 2000)	[mm/season]	(variation vs 2000)
February 1st	656.0	614.3	-6.3%	667.8	1.8%
February 15th	642.7	606.0	-5.7%	651.6	1.4%
March 1st	628.1	589.7	-6.1%	643.5	2.5%
March 15th	608.1	580.3	-4.6%	627.1	3.1%
April 1st	585.8	562.1	-4.1%	610.0	4.1%
average	624.1	590.5	-5.4%	640.0	2.5%

Tab. 92 – Effect of planting date and variety selection on the effective rainfall pattern during crop cycle of tomato in Nile Delta, Rosetta (Egypt) under “present” and “future” climate conditions.

Planting date	Rain_eff 2000	Rain_eff 2050		Rain_eff 2050 late_var	
	[mm/season]	[mm/season]	(variation vs 2000)	[mm/season]	(variation vs 2000)
February 1st	15.3	11.6	-24.1%	11.6	-24.1%
February 15th	15.3	11.6	-24.1%	11.6	-24.1%
March 1st	9.5	9.2	-2.4%	9.2	-2.4%
March 15th	6.6	6.9	4.7%	6.9	4.7%
April 1st	3.1	6.9	121.5%	6.9	121.5%
average	9.9	9.2	-7.1%	9.2	-7.1%

Tab. 93 – Effect of irrigation strategies and variety selection on the effective evapotranspiration of tomato in Nile Delta, Rosetta (Egypt) under “present” and “future” climate conditions.

Irrigation strategy	ETc_eff 2000	ETc_eff 2050		ETc_eff 2050 late_var	
	[mm/season]	[mm/season]	(variation vs 2000)	[mm/season]	(variation vs 2000)
full	624.1	590.5	-5.4%	639.9	2.5%
mild1	598.8	565.5	-5.6%	613.2	2.4%
mild2	542.0	514.6	-5.1%	554.3	2.3%
medium	527.2	495.2	-6.1%	540.6	2.5%
severe1	442.2	420.1	-5.0%	451.0	2.0%
severe2	335.7	318.9	-5.0%	341.6	1.8%
rainfed	143.0	141.2	-1.2%	141.5	-1.0%

Tab. 94 – Effect of irrigation strategies and variety selection on the net irrigation requirements of tomato in Nile Delta, Rosetta (Egypt) under “present” and “future” climate conditions.

Irrigation strategy	NIR 2000	NIR 2050		NIR 2050 late_var	
	[mm/season]	[mm/season]	(variation vs 2000)	[mm/season]	(variation vs 2000)
full	591.8	554.4	-6.3%	603.9	2.1%
mild1	536.6	507.2	-5.5%	551.4	2.7%
mild2	473.4	443.5	-6.3%	483.2	2.1%
medium	448.0	421.3	-6.0%	457.6	2.1%
severe1	348.8	329.7	-5.5%	358.4	2.7%
severe2	224.0	210.6	-6.0%	228.8	2.1%
rainfed	0.0	0.0	0.0%	0.0	0.0%

- by plotting together the values of seasonal ETc_{eff} and NIR (obtained under different irrigation strategies and variety) for different climate scenarios, there is a clear prediction of their reduction (respectively of about -5.4% and -6.1%, on average) while, by considering a late maturing variety, only a slight increase of both is predicted (respectively of about +2.2% and +2.2%, on average) (fig. 71);
- the cumulative curves of ETc_{max} in 2050 (versus 2000) show always (especially for earlier planting dates) a clear shifting towards higher values, thus representing the relative increase in the daily crop water requirements, although with a decrease in the cumulative final value (depending on the anticipated ending of the cycle) (fig. 73).

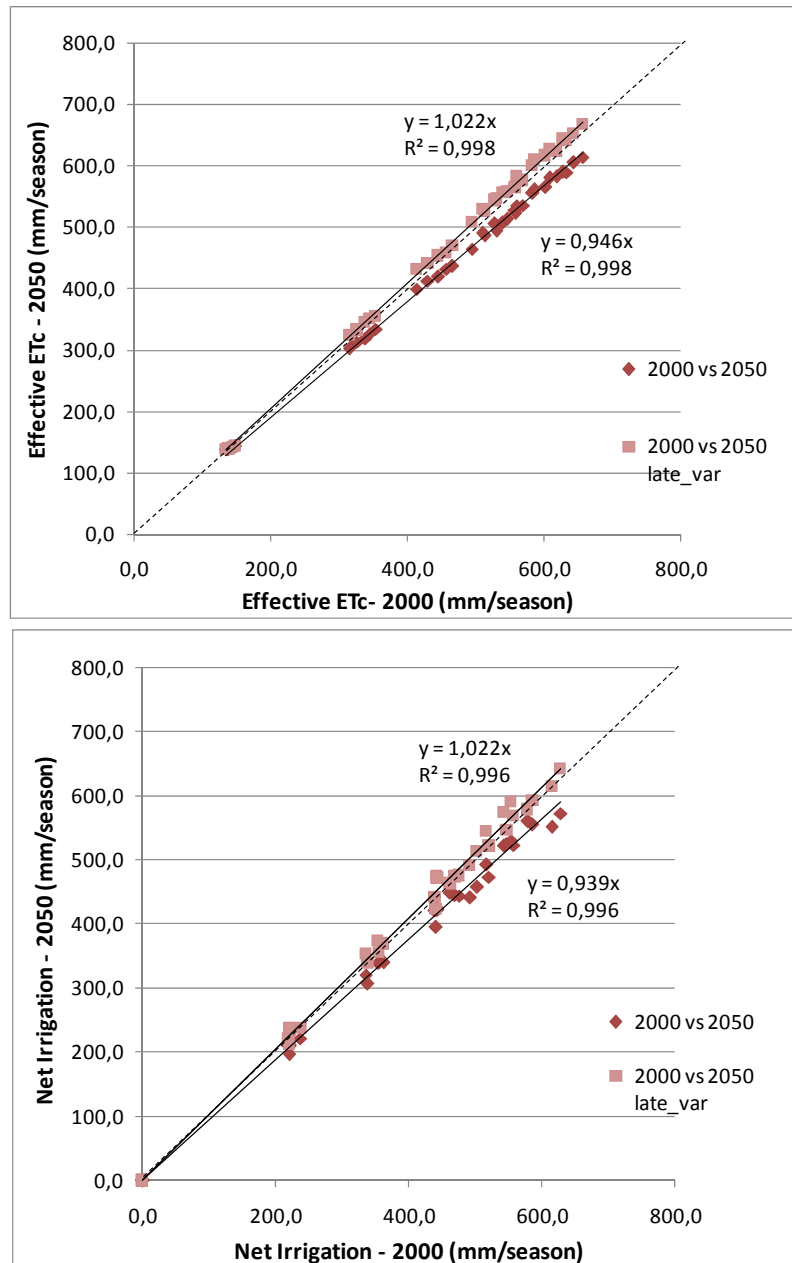


Fig. 71 – Scatter-plot of seasonal crop evapotranspiration and net irrigation requirements of as affected by different variety selection for tomato in Nile Delta, Rosetta (Egypt) under “present” and “future” climate conditions.

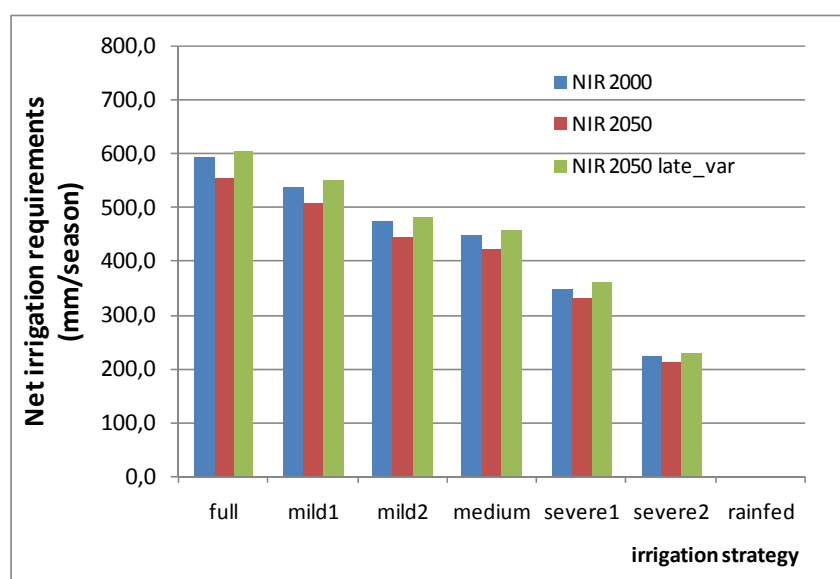
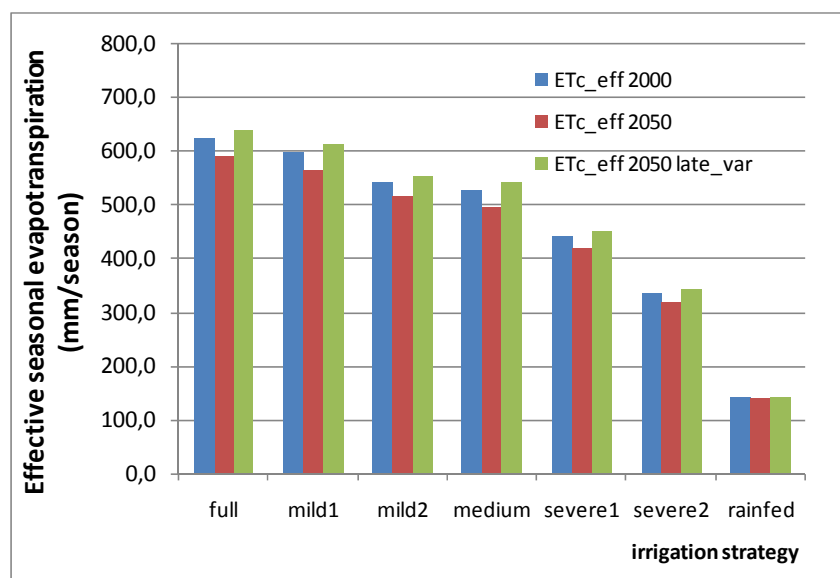
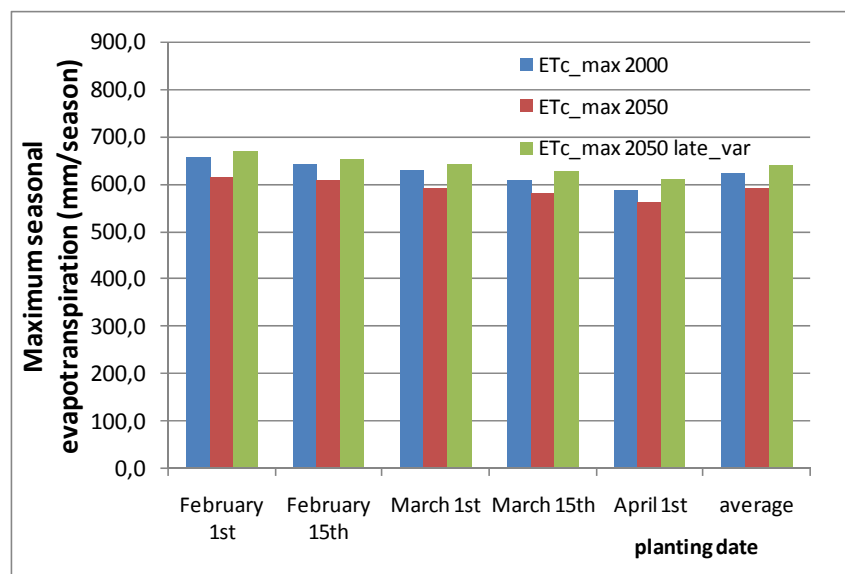


Fig. 72 – Effect of planting date, irrigation strategies and variety selection on maximum and effective crop evapotranspiration and net irrigation requirements of tomato in Nile Delta, Rosetta (Egypt) under “present” and “future” climate conditions.

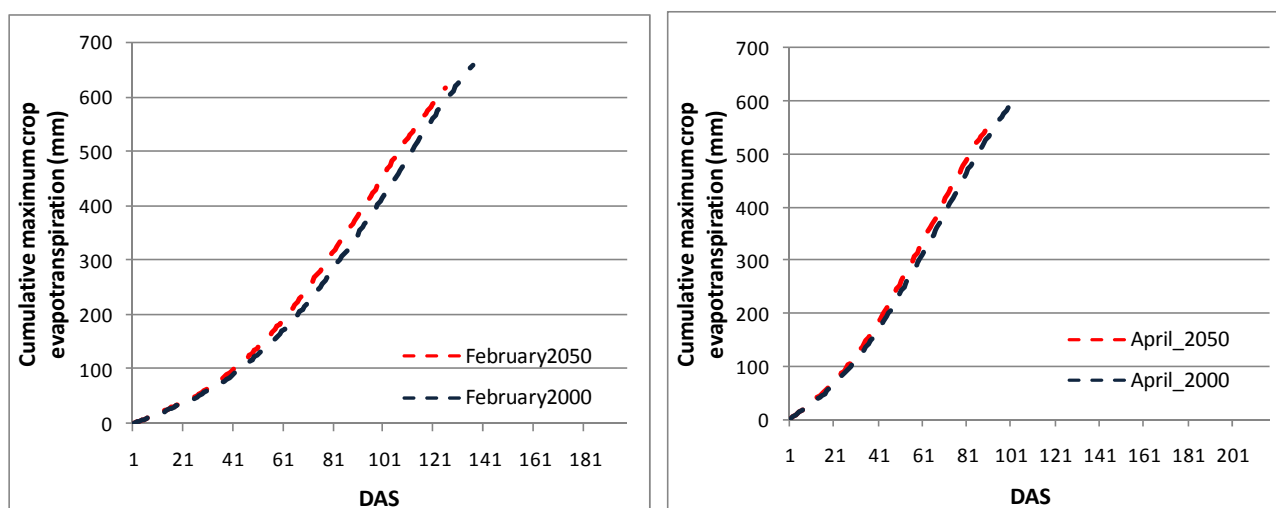


Fig. 73 – Cumulative curves of maximum crop evapotranspiration as affected by different planting date for tomato in Nile Delta, Rosetta (Egypt) under “present” and “future” climate conditions.

5.3.3. Yield response to water

The impact of climate change on potential yield, also considering the relative effect of selected adaptation strategies (planting dates, variety selection and deficit irrigation strategies), is summarized in the following tables and graphs. In brief, the following observations are reported:

- yield is projected to reduce under “future” scenario (2050) with respect to current conditions (2000), on average from 62.4 to 59.1 t ha⁻¹ (about -5.4%), depending on irrigation strategies (tab. 95 and fig.74) and planting dates (tab. 96 and fig.74) as a consequence of the expected shortening of the crop growing cycle;
- on the contrary, if the expected fertilizing effect due to an increase in atmospheric CO₂ concentration will occur, yield (2050 wp_adj) is projected to increase in quite all conditions (with an average of 70.9 t ha⁻¹, +13.5%), and thus to overcome the effect of the shortening of the crop cycle (fig. 74 and tab. 95-96);
- on the other side, if a late maturing variety (2050 late_var) is selected, yield is projected to increase (with an average of 64.0 t ha⁻¹, +2.5%), especially under fully irrigation and late planting dates (fig. 74 and tab.95-96);
- there is a clear reduction in potential yield under increasing water stress conditions (fig.74), and under “severe” water stress (thus only supported by supplemental irrigations) values of 12-30 t ha⁻¹ are predicted; in the case of rainfed conditions, according to the model used, no yield is expected in all conditions;
- yield is observed always to slightly decrease (in absolute terms) for late (April) planting date with respect to earlier (February) ones (fig. 74), because of the shortening of the growing cycle due to its shifting in the hotter summer.

Tab. 95 – Effect of irrigation strategies, variety selection and atmospheric CO₂ increase on the potential yield of tomato in Nile Delta, Rosetta (Egypt) under “present” and “future” climate conditions.

Irrigation strategy	Yield 2000 (*)	Yield 2050 (*)		Yield 2050 wp_adj (**)		Yield 2050 late_var (*)	
	(t/ha)	(t/ha)	(variation vs 2000)	(t/ha)	(variation vs 2000)	(t/ha)	(variation vs 2000)
full	62.4	59.1	-5.4%	70.9	13.5%	64.0	2.5%
mild1	57.1	53.7	-5.9%	64.5	12.9%	58.2	1.9%
mild2	43.0	41.1	-4.4%	49.3	14.7%	44.0	2.3%
medium	43.7	41.3	-5.6%	49.5	13.3%	44.9	2.7%
severe1	26.8	25.8	-3.7%	31.0	15.6%	27.3	2.0%
severe2	14.2	13.9	-2.3%	16.7	17.2%	14.5	2.2%
rainfed	0.0	0.0		0.0		0.0	
(*) assuming wp (2000) = 10 (kg/m3)							
(**) assuming wp (2050)= wp(2000)*1.2= 12 (kg/m3)							

Tab. 96 – Effect of planting date, variety selection and atmospheric CO₂ increase on the potential yield of tomato in Nile Delta, Rosetta (Egypt) under “present” and “future” climate conditions.

Irrigation strategy	Yield 2000 (*)	Yield 2050 (*)		Yield 2050 wp_adj (**)		Yield 2050 late_var (*)	
	(t/ha)	(t/ha)	(variation vs 2000)	(t/ha)	(variation vs 2000)	(t/ha)	(variation vs 2000)
Febr 1st	65.6	61.4	-6.3%	73.7	12.4%	66.8	1.8%
Febr 15th	64.3	60.6	-5.7%	72.7	13.1%	65.2	1.4%
March 1st	62.8	59.0	-6.1%	70.8	12.7%	64.3	2.5%
March 15th	60.8	58.0	-4.6%	69.6	14.5%	62.7	3.1%
April 1st	58.6	56.2	-4.1%	67.5	15.1%	61.0	4.1%
average	62.4	59.1	-5.4%	70.9	13.5%	64.0	2.5%
(*) assuming wp (2000) = 10 (kg/m3)							
(**) assuming wp (2050)= wp(2000)*1.2= 12 (kg/m3)							

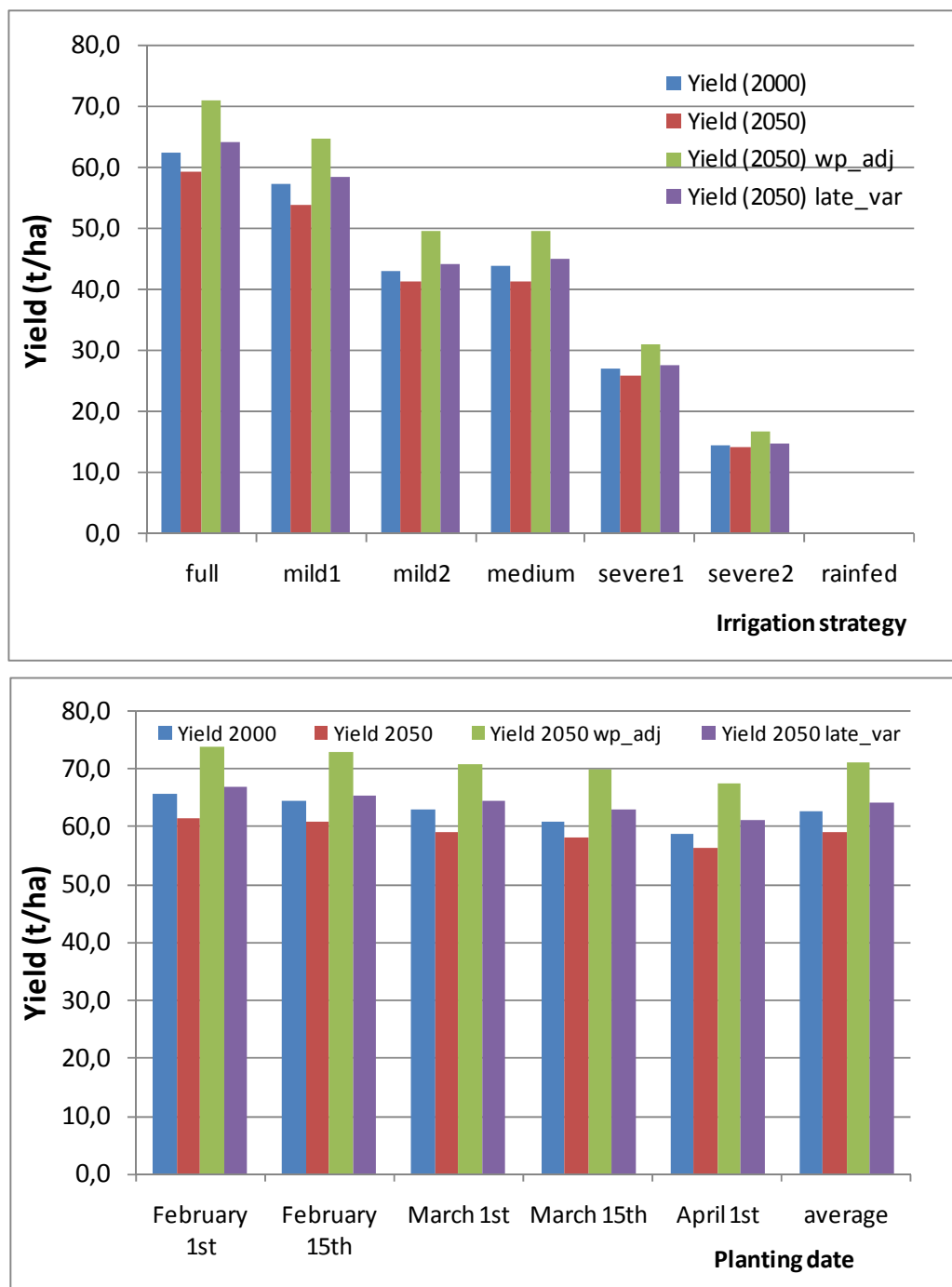


Fig. 74 – Effect of planting date, irrigation strategies, variety selection and atmospheric CO₂ increase on potential yield of tomato in Nile Delta, Rosetta (Egypt) under “present” and “future” climate conditions.

5.4. Potato

5.4.1. Cycle length and crop coefficient curves

The effect of temperature increase (and relative GDD accumulation) on current and projected crop cycle length and corresponding crop coefficient curves is represented in the following graphs, and the following observations have to be highlighted:

- if varietal adaptation is not considered, an important reduction of the total growing cycle is predicted for all planting dates, because of the faster accumulation of the required GGD sum under “future” climate conditions (2050) (fig. 75-76);
- if a late maturing variety will be used, the total crop cycle length (2050 late_var) is projected to remain relatively the same as for the current variety under “present” climate conditions (2000), especially for late planting dates (fig. 76);
- with respect to the four crop coefficient stages, a relative reduction is predicted in proportion to the corresponding increase in the cumulative GDD (lower during winter, higher during spring-summer months), but with a greater effect in the case of early (October) rather than late (February) planting dates (fig. 75).

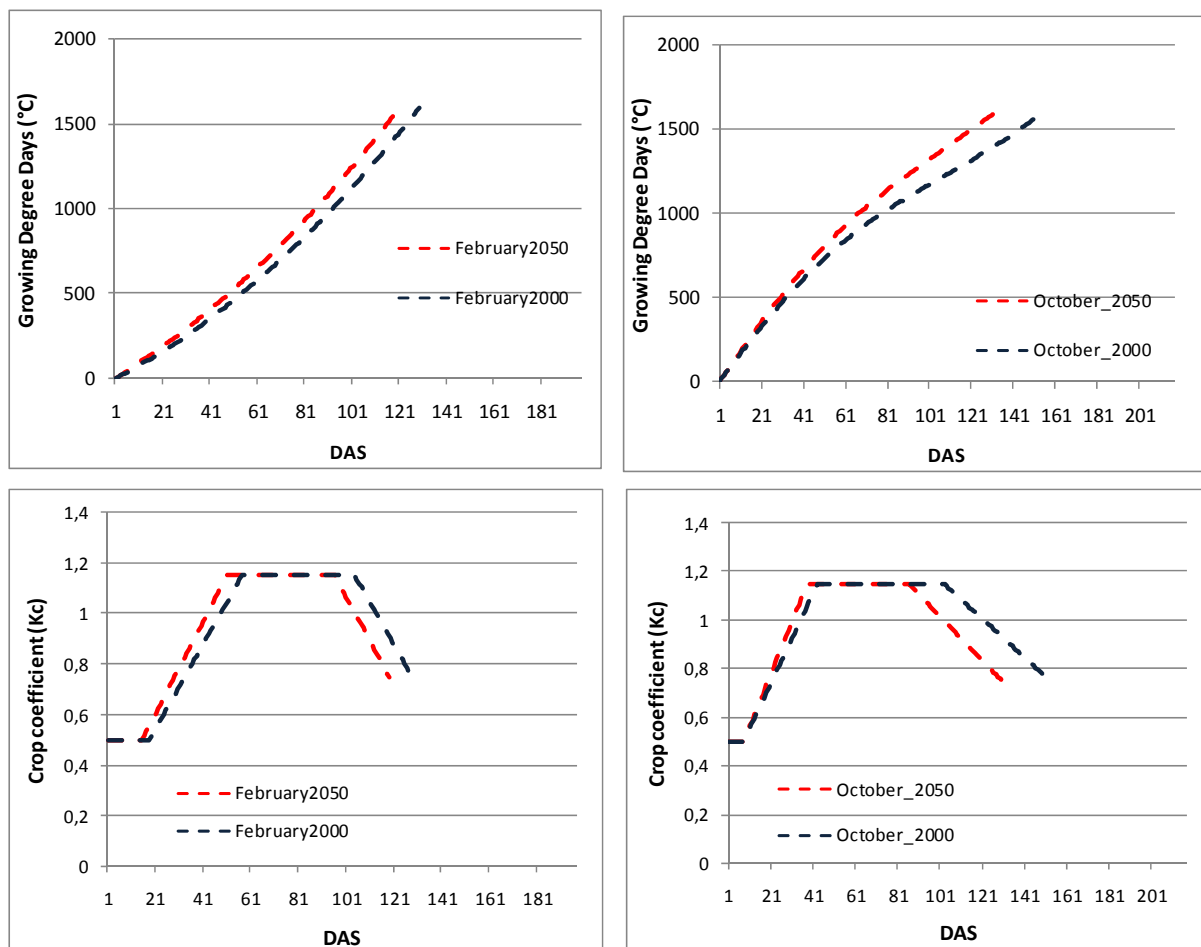


Fig. 75 – Predicted cumulative GDD and corresponding Kc curves for potato in Nile Delta, Rosetta (Egypt) as affected by different planting dates and climate scenarios.

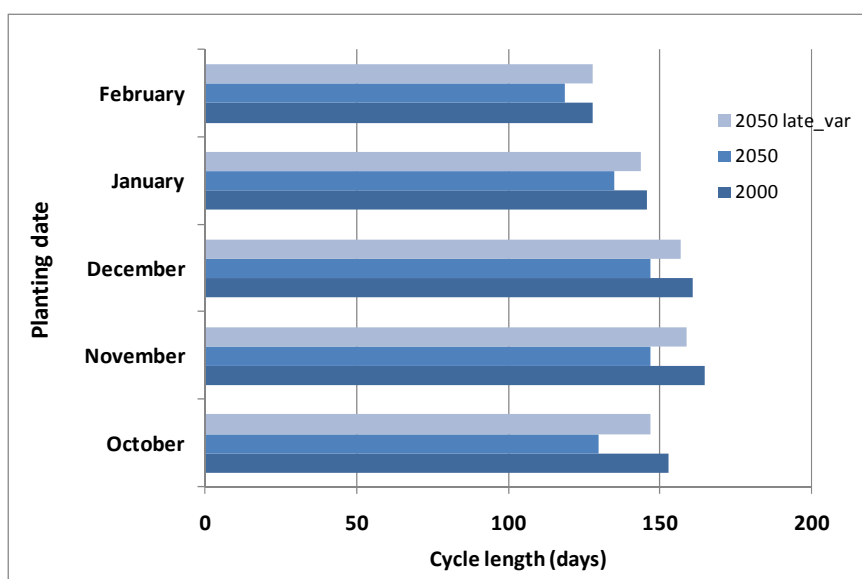


Fig. 76 – Length of total growing cycle of potato in Nile Delta, Rosetta (Egypt) as affected by planting date, variety selection and climate variations.

5.4.2. Crop evapotranspiration and irrigation requirements

The impact of climate change on maximum and effective crop evapotranspiration as well as on net irrigation requirements, also considering the relative effect of selected adaptation strategies (planting dates, variety selection and deficit irrigation strategies), is summarized in the following tables and graphs. In brief, the following observations are reported:

- maximum seasonal crop evapotranspiration is projected to reduce for the current variety under “future” (2050) scenario as a consequence of the expected shortening of the crop growing cycle, on average of about -9.6% with respect to current conditions (2000) (fig. 78 and tab. 97);
- on the contrary, if a late maturing variety (2050 late_var) is selected, maximum evapotranspiration is projected to slightly increase (on average of about 1.1%) (fig. 78 and tab. 97);
- the relative effect of the projected variation of rainfall patterns seems slightly important for the crop water balance, with an average reduction of about -8.4 mm during cropping cycle (tab.98);
- maximum seasonal crop evapotranspiration is observed always to increase (in absolute terms) towards a peak of planting date of February with respect to earlier ones (fig. 78 and tab.97);
- effective seasonal crop evapotranspiration and net irrigation requirements are both highly dependent on the irrigation strategy, progressively reducing going from full irrigation to rainfed conditions (fig. 78 and tab.99-100);
- as for ET_{c_max} , also the ET_{c_eff} and NIR are projected to decrease in 2050 if the current variety is used; on the other side, if a late maturing variety is selected, while ET_{c_eff} is projected to remain relatively stable, NIR is always projected to increase (fig. 78 and tab.99-100);

Tab. 97 – Effect of planting date and variety selection on the maximum crop evapotranspiration of potato in Nile Delta, Rosetta (Egypt) under “present” and “future” climate conditions.

Planting date	ETc_max 2000	ETc_max 2050		ETc_max 2050 late_var	
	[mm/season]	[mm/season]	(variation vs 2000)	[mm/season]	(variation vs 2000)
october	431.4	373.6	-13.4%	426.5	-1.1%
november	524.0	451.1	-13.9%	513.0	-2.1%
december	583.0	525.1	-9.9%	585.0	0.3%
january	586.9	543.5	-7.4%	602.4	2.6%
february	607.9	576.1	-5.2%	635.4	4.5%
average	546.6	493.9	-9.6%	552.5	1.1%

Tab. 98 – Effect of planting date and variety selection on the effective rainfall pattern during crop cycle of potato in Nile Delta, Rosetta (Egypt) under “present” and “future” climate conditions.

Planting date	Rain_eff 2000	Rain_eff 2050		Rain_eff 2050 late_var	
	[mm/season]	[mm/season]	(variation vs 2000)	[mm/season]	(variation vs 2000)
october	53.8	43.3	-19.6%	45.6	-15.2%
november	56.5	37.9	-32.9%	37.9	-32.9%
december	41.3	34.4	-16.6%	35.7	-13.5%
january	20.3	18.0	-11.5%	18.0	-11.5%
february	15.3	11.6	-24.1%	11.6	-24.1%
average	37.4	29.0	-22.4%	29.8	-20.5%

Tab. 99 – Effect of irrigation strategies and variety selection on the effective evapotranspiration of potato in Nile Delta, Rosetta (Egypt) under “present” and “future” climate conditions.

Irrigation strategy	ETc_eff 2000	ETc_eff 2050		ETc_eff 2050 late_var	
	[mm/season]	[mm/season]	(variation vs 2000)	[mm/season]	(variation vs 2000)
full	546.4	493.7	-9.6%	552.3	1.1%
mild1	515.8	466.6	-9.5%	522.4	1.3%
mild2	469.7	425.9	-9.3%	472.8	0.7%
medium	451.9	407.8	-9.8%	457.0	1.1%
severe1	379.4	343.9	-9.4%	380.7	0.3%
severe2	287.3	260.2	-9.5%	285.7	-0.6%
rainfed	122.6	112.4	-8.4%	114.3	-6.8%

Tab. 100 – Effect of irrigation strategies and variety selection on the net irrigation requirements of potato in Nile Delta, Rosetta (Egypt) under “present” and “future” climate conditions.

Irrigation strategy	NIR 2000	NIR 2050		NIR 2050 late_var	
	[mm/season]	[mm/season]	(variation vs 2000)	[mm/season]	(variation vs 2000)
full	498.5	451.6	-9.4%	508.5	2.0%
mild1	450.3	408.1	-9.4%	460.8	2.3%
mild2	398.8	361.3	-9.4%	406.8	2.0%
medium	376.7	344.4	-8.6%	395.8	5.1%
severe1	292.7	265.2	-9.4%	299.5	2.3%
severe2	188.3	172.2	-8.6%	197.9	5.1%
rainfed	0.0	0.0	0.0%	0.0	0.0%

- by plotting together the values of seasonal ETc_{eff} and NIR (obtained under different irrigation strategies and variety) for different climate scenarios, there is a clear prediction of their reduction (respectively of about -9.3% and -9.1%, on average) and, by considering a late maturing variety, a relative stability or slight increase of both is predicted (respectively of about 0.9% and 2.9%, on average) (fig. 77);
- the cumulative curves of ETc_{max} in 2050 (versus 2000) show always a clear shifting towards higher values, thus representing the relative increase in the daily crop water requirements, although with a decrease in the cumulative final value (depending on the anticipated ending of the cycle) (fig.79).

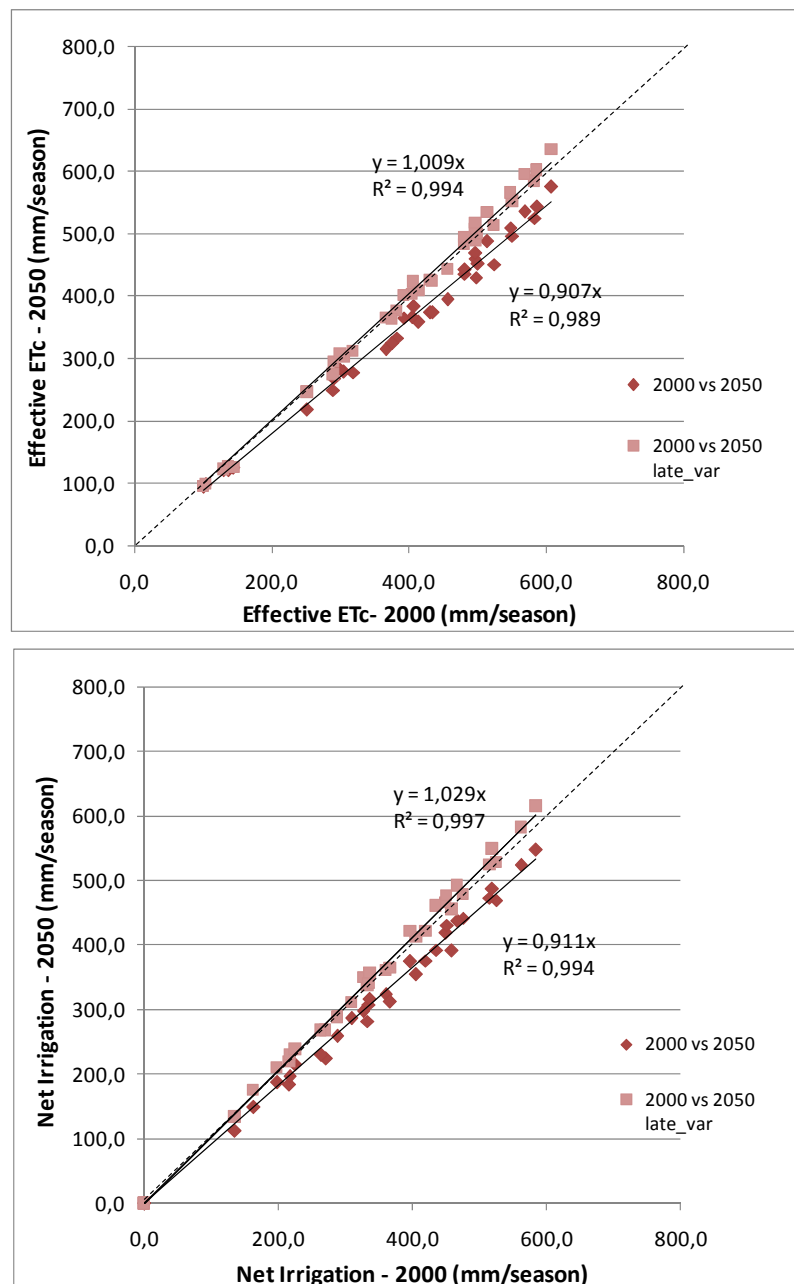


Fig. 77 – Scatter-plot of seasonal crop evapotranspiration and net irrigation requirements of as affected by different variety selection for potato in Nile Delta, Rosetta (Egypt) under “present” and “future” climate conditions.

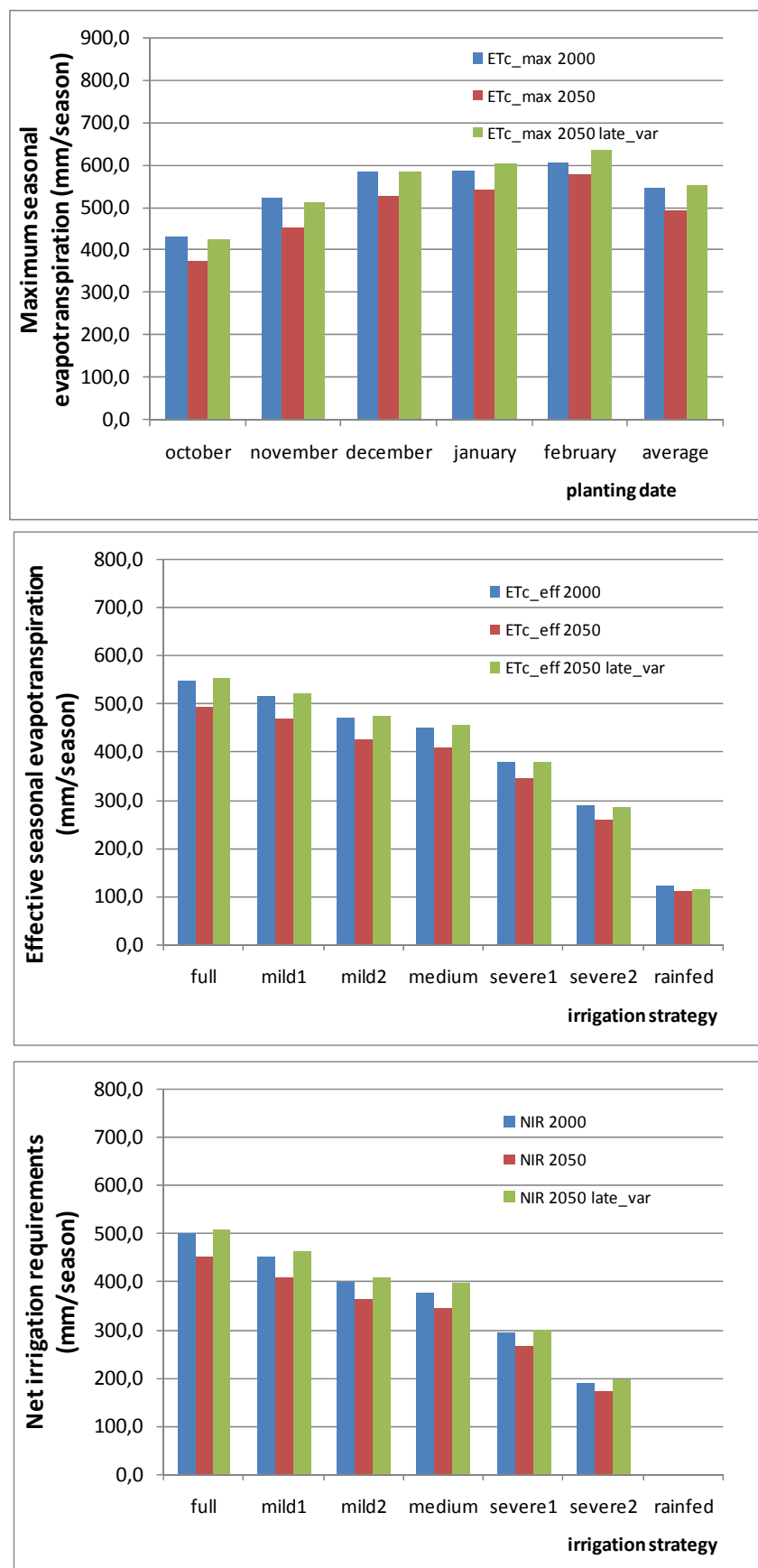


Fig. 78 – Effect of planting date, irrigation strategies and variety selection on maximum and effective crop evapotranspiration and net irrigation requirements of potato in Nile Delta, Rosetta (Egypt) under “present” and “future” climate conditions.

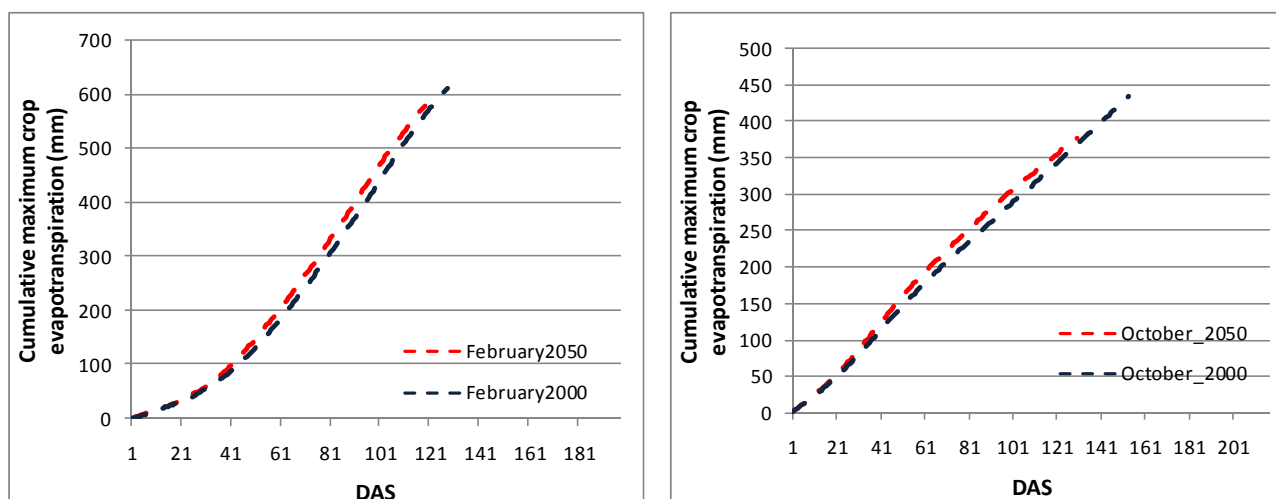


Fig. 79 – Cumulative curves of maximum crop evapotranspiration as affected by different planting date for potato in Nile Delta, Rosetta (Egypt) under “present” and “future” climate conditions.

5.4.3. Yield response to water

The impact of climate change on potential yield, also considering the relative effect of selected adaptation strategies (planting dates, variety selection and deficit irrigation strategies), is summarized in the following tables and graphs. In brief, the following observations are reported:

- yield is projected to reduce under “future” scenario (2050) with respect to current conditions (2000), on average from 32.8 to 29.6 t ha⁻¹ (about -9.6%), depending on irrigation strategies (tab. 101 and fig.80) and planting dates (tab. 102 and fig.80), as a consequence of the expected shortening of the crop growing cycle;
- on the contrary, if the expected fertilizing effect due to an increase in atmospheric CO₂ concentration will occur, yield (2050 wp_adj) is projected to increase in quite all conditions (with an average of 35.6 t ha⁻¹, +8.4%), and thus to overcome the effect of the shortening of the crop cycle (fig. 80 and tab.101-102);
- on the other side, if a late maturing variety (2050 late_var) is selected, yield is projected to slightly increase (with an average of 33.1 t ha⁻¹, 1.1%), depending on irrigation strategy and planting dates (fig. 80 and tab.101-102);
- there is a clear reduction in potential yield under increasing water stress conditions (fig.80), and under “severe” water stress (thus only supported by supplemental irrigations) values of 15-20 t ha⁻¹ are predicted;
- in the case of rainfed conditions, very low yield (around 7 t ha⁻¹) is expected in all conditions;
- yield is observed always to increase (in absolute terms) for winter planting dates with respect to earlier (October) ones (fig.80), because of the corresponding increase in total maximum crop evapotranspiration.

Tab. 101 – Effect of irrigation strategies, variety selection and atmospheric CO₂ increase on the potential yield of potato in Nile Delta, Rosetta (Egypt) under “present” and “future” climate conditions.

Irrigation strategy	Yield 2000 (*)	Yield 2050 (*)		Yield 2050 wp_adj (**)		Yield 2050 late_var (*)	
	(t/ha)	(t/ha)	(variation vs 2000)	(t/ha)	(variation vs 2000)	(t/ha)	(variation vs 2000)
full	32.8	29.6	-9.6%	35.6	8.4%	33.1	1.1%
mild1	30.5	27.6	-9.6%	33.1	8.5%	30.8	1.0%
mild2	27.1	24.7	-8.9%	29.7	9.3%	27.2	0.3%
medium	25.3	22.9	-9.6%	27.5	8.5%	25.7	1.5%
severe1	20.4	18.6	-8.9%	22.3	9.3%	20.3	-0.4%
severe2	14.6	13.3	-8.7%	16.0	9.6%	14.4	-1.1%
rainfed	7.0	6.5	-7.4%	7.8	11.2%	6.6	-5.7%
(*) assuming wp (2000) = 6 (kg/m3)							
(**) assuming wp (2050)= wp(2000)*1.2= 7.2 (kg/m3)							

Tab. 102 – Effect of planting date, variety selection and atmospheric CO₂ increase on the potential yield of potato in Nile Delta, Rosetta (Egypt) under “present” and “future” climate conditions.

Irrigation strategy	Yield 2000 (*)	Yield 2050 (*)		Yield 2050 wp_adj (**)		Yield 2050 late_var (*)	
	(t/ha)	(t/ha)	(variation vs 2000)	(t/ha)	(variation vs 2000)	(t/ha)	(variation vs 2000)
october	25.9	22.4	-13.4%	26.9	3.9%	25.6	-1.1%
november	31.4	27.1	-13.9%	32.5	3.3%	30.8	-2.1%
december	35.0	31.5	-9.9%	37.8	8.1%	35.1	0.3%
january	35.2	32.6	-7.4%	39.1	11.1%	36.1	2.6%
february	36.5	34.6	-5.2%	41.5	13.7%	38.1	4.5%
average	32.8	29.6	-9.6%	35.6	8.4%	33.1	1.1%
(*) assuming wp (2000) = 6 (kg/m3)							
(**) assuming wp (2050)= wp(2000)*1.2= 7.2 (kg/m3)							

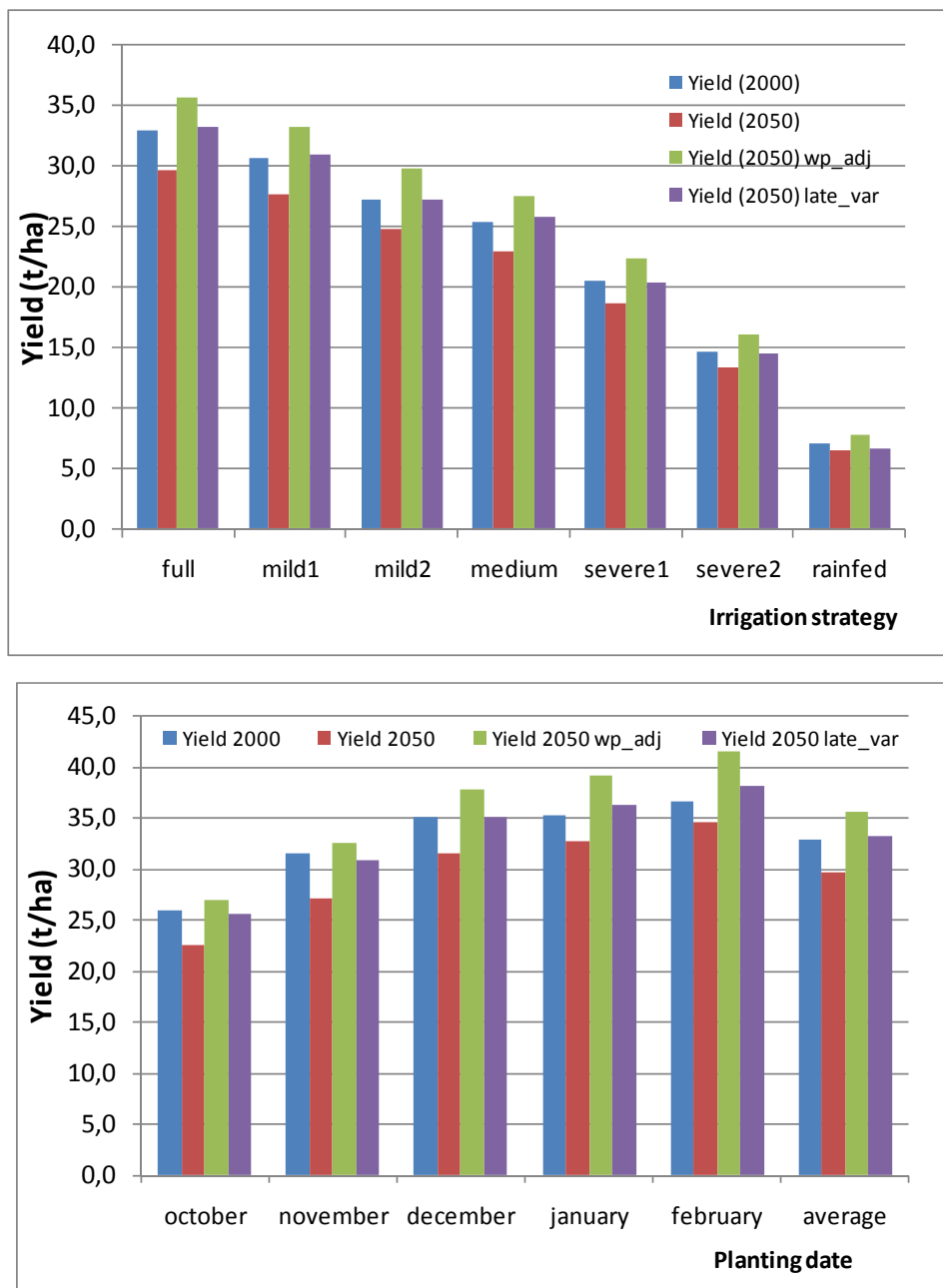


Fig. 80 – Effect of planting date, irrigation strategies, variety selection and atmospheric CO₂ increase on potential yield of potato in Nile Delta, Rosetta (Egypt) under “present” and “future” climate conditions.

5.5. Maize

5.5.1. Cycle length and crop coefficient curves

The effect of temperature increase (and relative GDD accumulation) on current and projected crop cycle length and corresponding crop coefficient curves is represented in the following graphs, and the following observations have to be highlighted:

- if varietal adaptation is not considered, an important reduction of the total growing cycle is predicted for all planting dates, because of the faster accumulation of the required GGD sum under “future” climate conditions (2050) (fig. 81-82);
- if a late maturing variety will be used, the total crop cycle length (2050 late_var) is projected to remain relatively the same as for the current variety under “present” climate conditions (2000) (fig. 82);
- with respect to the four crop coefficient stages, a relative reduction is predicted in proportion to the corresponding increase in the cumulative GDD, with a relatively greater effect in the case of early (March) rather than late (May) planting dates (fig. 81).

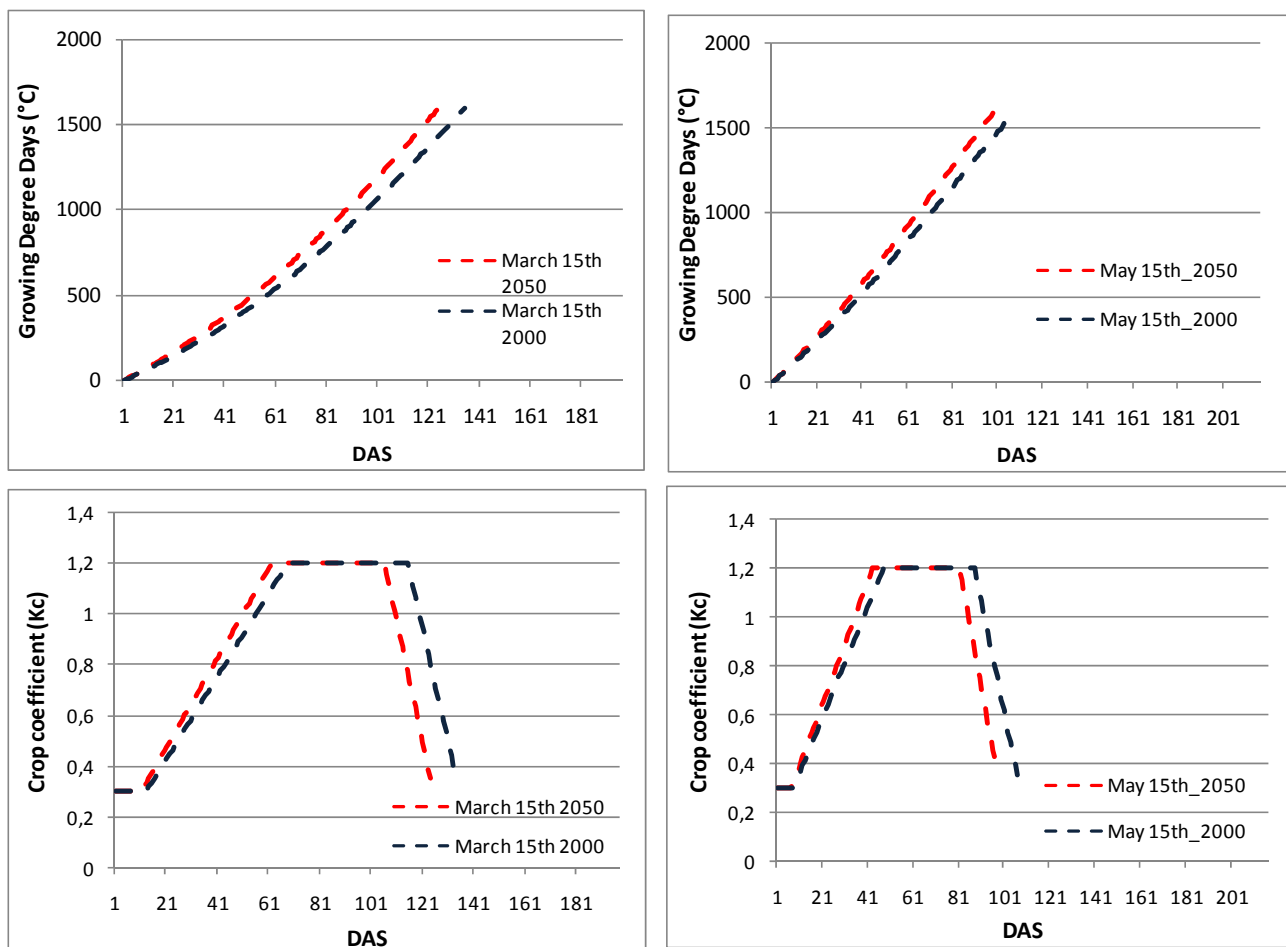


Fig. 81 – Predicted cumulative GDD and corresponding Kc curves for maize in Nile Delta, Rosetta (Egypt) as affected by different planting dates and climate scenarios.

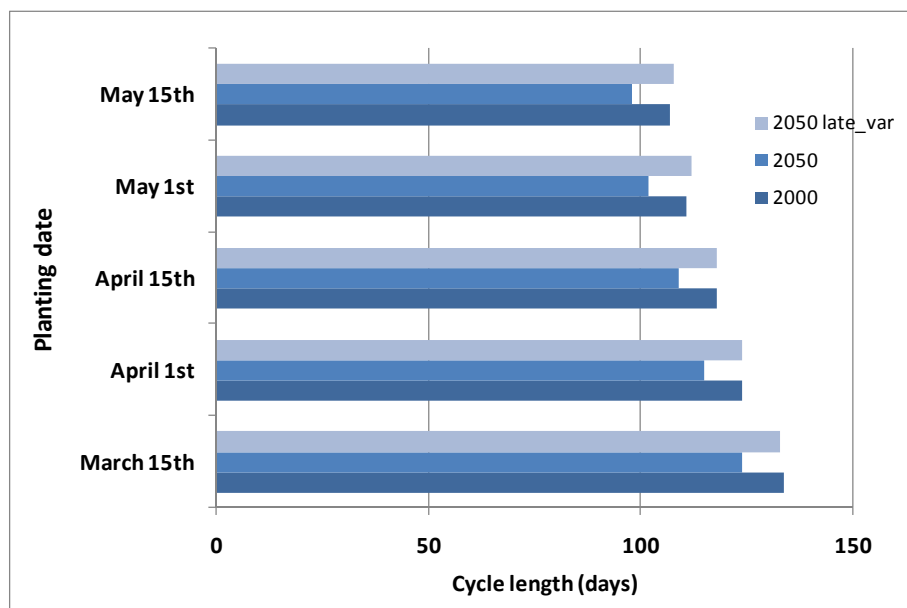


Fig. 82 – Length of total cycle length of maize in Nile Delta, Rosetta (Egypt) as affected by planting date, variety selection and climate variations.

5.5.2. Crop evapotranspiration and irrigation requirements

The impact of climate change on maximum and effective crop evapotranspiration as well as on net irrigation requirements, also considering the relative effect of selected adaptation strategies (planting dates, variety selection and deficit irrigation strategies), is summarized in the following tables and graphs. In brief, the following observations are reported:

- maximum seasonal crop evapotranspiration is projected to reduce for the current variety under “future” (2050) scenario as a consequence of the expected shortening of the crop growing cycle, on average of about -4.0% with respect to current conditions (2000) (fig.84 and tab. 103);
- on the contrary, if a late maturing variety (2050 late_var) is selected, maximum evapotranspiration is projected to increase (on average of about 4.1%) (fig. 84 and tab.103);
- the relative effect of the projected variation of rainfall patterns seems irrelevant for the crop water balance, because of the very low values considered (tab.104);
- maximum seasonal crop evapotranspiration is observed always to increase (in absolute terms) for earlier planting dates (March) with respect to later ones, probably because of the longer growing cycle (fig.84 and tab.103);
- effective seasonal crop evapotranspiration and net irrigation requirements are both highly dependent on the irrigation strategy, progressively reducing going from full irrigation to rainfed conditions (fig. 84 and tab.105-106);
- as for ET_{c_max} , also the ET_{c_eff} and NIR are projected to decrease in 2050 if the current variety is used; on the other side, , if a late maturing variety is selected, both are projected to increase (fig. 84 and tab.105-106);

Tab.103 – Effect of planting date and variety selection on the maximum crop evapotranspiration of maize in Nile Delta, Rosetta (Egypt) under “present” and “future” climate conditions.

Planting date	ETc_max 2000	ETc_max 2050		ETc_max 2050 late_var	
	[mm/season]	[mm/season]	(variation vs 2000)	[mm/season]	(variation vs 2000)
March 15th	732.7	701.0	-4.3%	756.5	3.2%
April 1st	704.8	676.8	-4.0%	729.8	3.5%
April 15th	684.7	657.6	-4.0%	711.6	3.9%
May 1st	656.8	627.9	-4.4%	687.5	4.7%
May 15th	632.7	611.8	-3.3%	668.0	5.6%
average	682.4	655.0	-4.0%	710.7	4.1%

Tab. 104 – Effect of planting date and variety selection on the effective rainfall pattern during crop cycle of maize in Nile Delta, Rosetta (Egypt) under “present” and “future” climate conditions.

Planting date	Rain_eff 2000	Rain_eff 2050		Rain_eff 2050 late_var	
	[mm/season]	[mm/season]	(variation vs 2000)	[mm/season]	(variation vs 2000)
March 15th	8.5	9.0	5.5%	9.0	5.5%
April 1st	5.1	9.0	77.3%	9.0	77.3%
April 15th	5.1	4.9	-3.6%	7.3	43.7%
May 1st	6.0	6.0	0.9%	6.0	0.9%
May 15th	6.0	6.0	0.9%	8.2	37.0%
average	6.1	7.0	14.1%	7.9	29.0%

Tab. 105 – Effect of irrigation strategies and variety selection on the effective evapotranspiration of maize in Nile Delta, Rosetta (Egypt) under “present” and “future” climate conditions.

Irrigation strategy	ETc_eff 2000	ETc_eff 2050		ETc_eff 2050 late_var	
	[mm/season]	[mm/season]	(variation vs 2000)	[mm/season]	(variation vs 2000)
full	682.2	654.9	-4.0%	710.6	4.2%
mild1	654.4	625.9	-4.3%	678.4	3.7%
mild2	592.6	571.0	-3.6%	615.1	3.8%
medium	571.5	549.2	-3.9%	590.2	3.3%
severe1	479.8	461.8	-3.7%	496.1	3.4%
severe2	357.2	346.3	-3.0%	367.1	2.8%
rainfed	138.9	139.2	0.3%	140.1	0.9%

Tab. 106 – Effect of irrigation strategies and variety selection on the net irrigation requirements of maize in Nile Delta, Rosetta (Egypt) under “present” and “future” climate conditions.

Irrigation strategy	NIR 2000	NIR 2050		NIR 2050 late_var	
	[mm/season]	[mm/season]	(variation vs 2000)	[mm/season]	(variation vs 2000)
full	633.6	607.4	-4.1%	657.6	3.8%
mild1	586.1	563.8	-3.8%	614.1	4.8%
mild2	506.9	485.9	-4.1%	526.0	3.8%
medium	486.3	463.1	-4.8%	500.9	3.0%
severe1	381.0	366.5	-3.8%	399.2	4.8%
severe2	243.1	231.5	-4.8%	250.4	3.0%
rainfed	0.0	0.0	0.0%	0.0	0.0%

- by plotting together the values of seasonal ETc_{eff} and NIR (obtained under different irrigation strategies and variety) for different climate scenarios, there is a clear prediction of their reduction (respectively of about -5.9% and -4.3%, on average) while, by considering a late maturing variety they are projected to increase (respectively of about +3.5% and 3.8%) (fig. 83);
- the cumulative curves of ETc_{max} in 2050 (versus 2000) show always a clear shifting towards higher values, thus representing the relative increase in the daily crop water requirements, although with a decrease in the cumulative final value (depending on the anticipated ending of the cycle) (fig. 85).

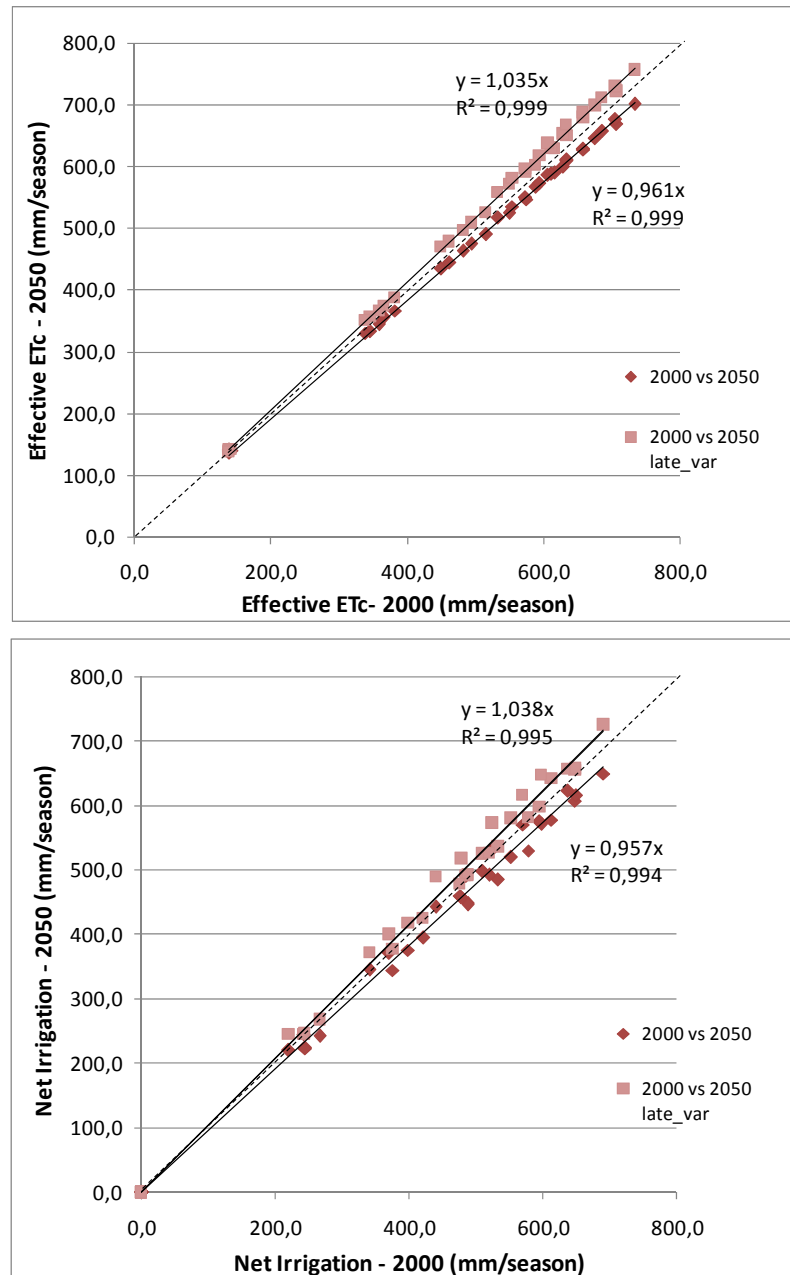


Fig. 83 – Scatter-plot of seasonal crop evapotranspiration and net irrigation requirements of as affected by different variety selection for maize in Nile Delta, Rosetta (Egypt) under “present” and “future” climate conditions.

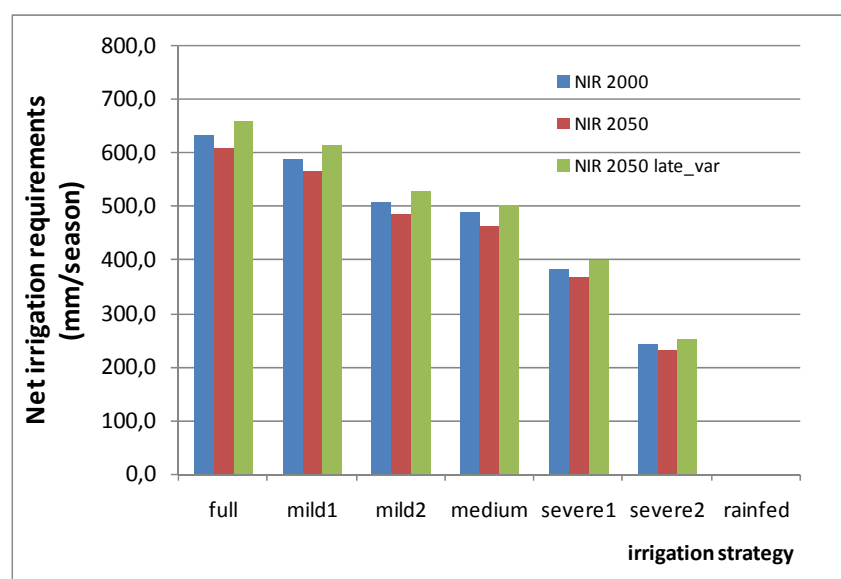
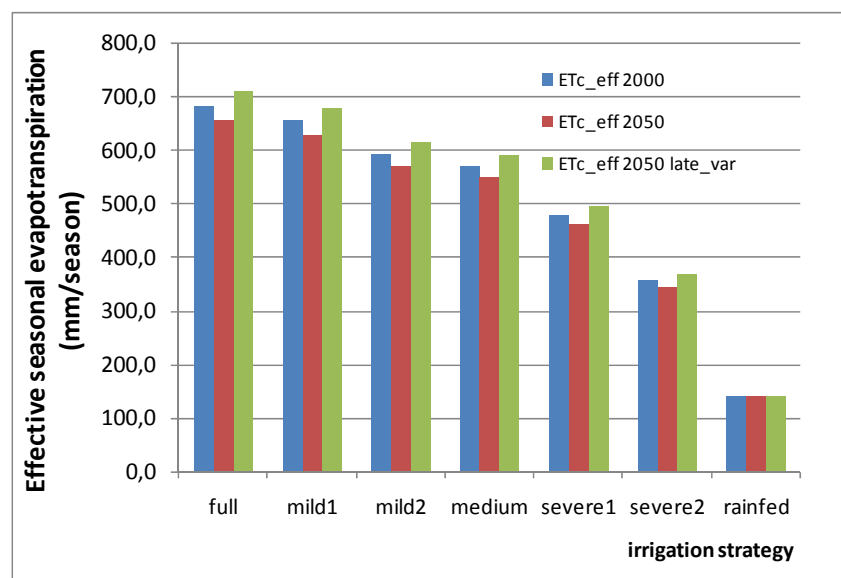
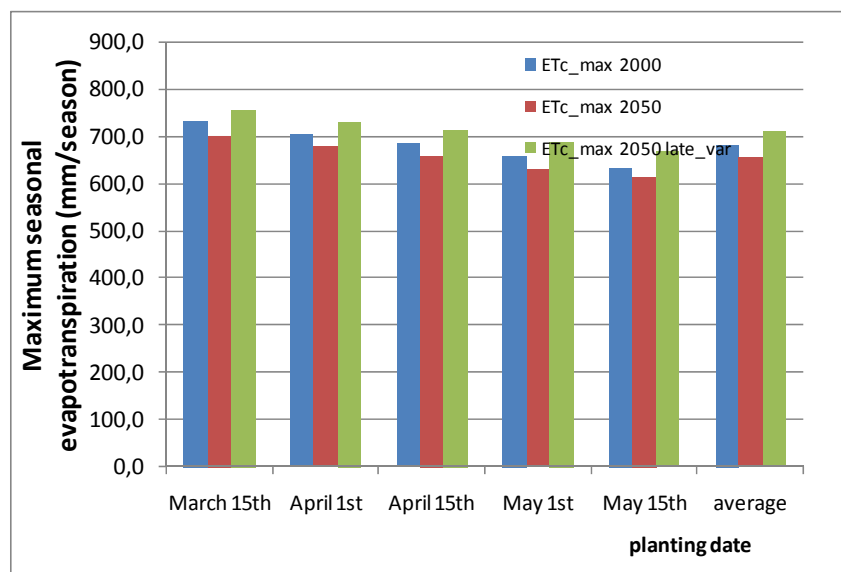


Fig. 84 – Effect of planting date, irrigation strategies and variety selection on maximum and effective crop evapotranspiration and net irrigation requirements of maize in Nile Delta, Rosetta (Egypt) under “present” and “future” climate conditions.

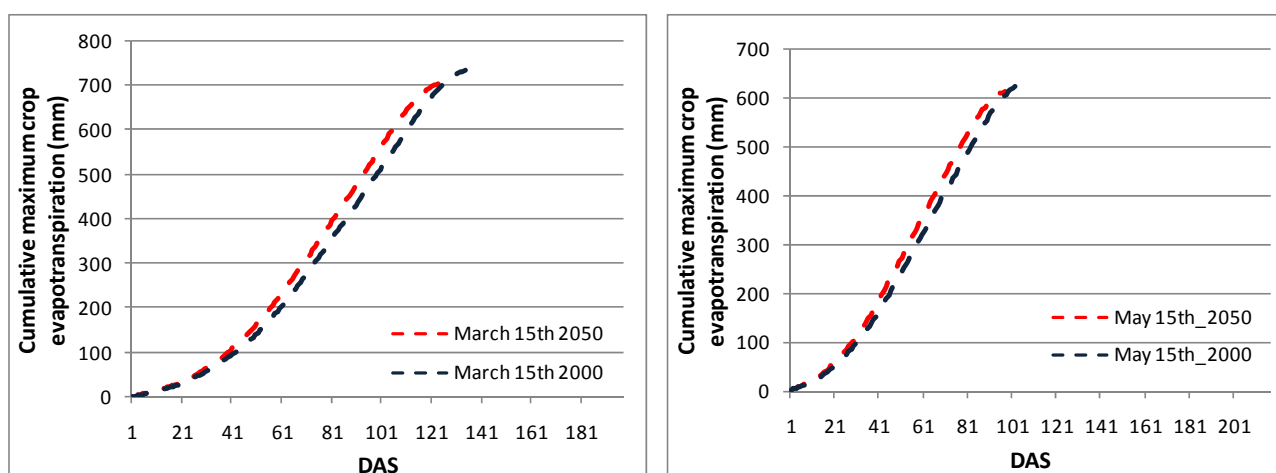


Fig. 85 – Cumulative curves of maximum crop evapotranspiration as affected by different planting date for maize in Nile Delta, Rosetta (Egypt) under “present” and “future” climate conditions.

5.5.3. Yield response to water

The impact of climate change on potential yield, also considering the relative effect of selected adaptation strategies (planting dates, variety selection and deficit irrigation strategies), is summarized in the following tables and graphs. In brief, the following observations are reported:

- yield is projected to reduce under “future” scenario (2050) with respect to current conditions (2000), on average from 8.9 to 8.5 t ha⁻¹ (about -4.0%), depending on irrigation strategies (tab. 107 and fig.86) and planting dates (tab.107 and fig.86), as a consequence of the expected shortening of the crop growing cycle;
- on the contrary, if the expected fertilizing effect due to an increase in atmospheric CO₂ concentration will occur, yield (2050 wp_adj) is projected to increase in quite all conditions (with an average of 10.2 t ha⁻¹, +15.2%), and thus to overcome the effect of the shortening of the crop cycle (fig. 86 and tab. 107-108);
- on the other side, if a late maturing variety (2050 late_var) is selected, yield is projected to slightly increase (with an average of 9.2 t ha⁻¹, +4.1%), depending on irrigation strategy and planting dates (fig. 86 and tab.107-108);
- there is a clear reduction in potential yield under increasing water stress conditions (fig.86), and under “severe” water stress (thus only supported by supplemental irrigations) values of 1.5-3.5 t ha⁻¹ are predicted;
- in the case of rainfed conditions, no yield is expected in all planting conditions;
- yield is observed always to increase (in absolute terms) for earlier planting dates with respect to later ones (fig.86), because of the corresponding increase in total maximum crop evapotranspiration.

Tab. 107 – Effect of irrigation strategies, variety selection and atmospheric CO₂ increase on the potential yield of maize in Nile Delta, Rosetta (Egypt) under “present” and “future” climate conditions.

Irrigation strategy	Yield 2000 (*) (t/ha)	Yield 2050 (*)		Yield 2050 wp_adj (**)		Yield 2050 late_var (*)	
		(t/ha)	(variation vs 2000)	(t/ha)	(variation vs 2000)	(t/ha)	(variation vs 2000)
full	8.9	8.5	-4.0%	10.2	15.2%	9.2	4.1%
mild1	7.9	7.6	-4.5%	9.1	14.6%	8.2	2.9%
mild2	6.0	5.8	-3.0%	7.0	16.4%	6.2	3.9%
medium	6.0	5.6	-6.5%	6.7	12.2%	6.1	1.7%
severe1	3.4	3.3	-2.5%	4.0	17.0%	3.5	3.0%
severe2	1.6	1.5	-4.7%	1.8	14.3%	1.6	0.2%
rainfed	0.0	0.0		0.0		0.0	
(*) assuming wp (2000) = 1.3 (kg/m3)							
(**) assuming wp (2050)= wp(2000)*1.2= 1.56 (kg/m3)							

Tab. 108 – Effect of planting date, variety selection and atmospheric CO₂ increase on the potential yield of maize in Nile Delta, Rosetta (Egypt) under “present” and “future” climate conditions.

Irrigation strategy	Yield 2000 (*) (t/ha)	Yield 2050 (*)		Yield 2050 wp_adj (**)		Yield 2050 late_var (*)	
		(t/ha)	(variation vs 2000)	(t/ha)	(variation vs 2000)	(t/ha)	(variation vs 2000)
March 15th	9.5	9.1	-4.3%	10.9	14.8%	9.8	3.2%
April 1st	9.2	8.8	-4.0%	10.6	15.2%	9.5	3.5%
April 15th	8.9	8.5	-4.0%	10.3	15.2%	9.3	3.9%
May 1st	8.5	8.2	-4.4%	9.8	14.7%	8.9	4.7%
May 15th	8.2	8.0	-3.3%	9.5	16.0%	8.7	5.6%
average	8.9	8.5	-4.0%	10.2	15.2%	9.2	4.1%
(*) assuming wp (2000) = 1.3 (kg/m3)							
(**) assuming wp (2050)= wp(2000)*1.2= 1.56 (kg/m3)							

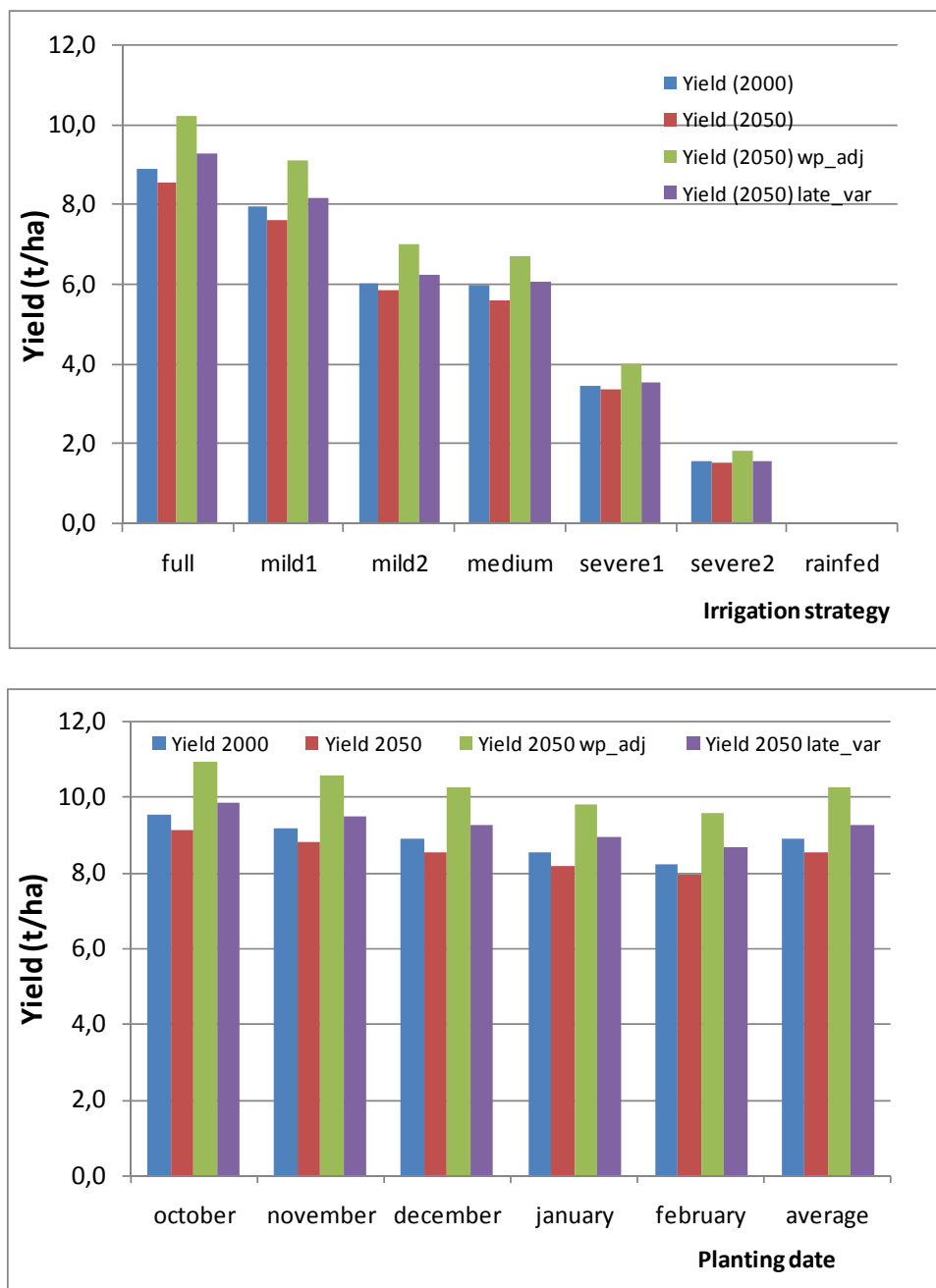


Fig. 86 – Effect of planting date, irrigation strategies, variety selection and atmospheric CO₂ increase on potential yield of maize in Nile Delta, Rosetta (Egypt) under “present” and “future” climate conditions.

6. Case study: Syros Island (Greece)

6.1. Climate projections and reference evapotranspiration

With respect to climate projections, as summarized in the following tables and graphs, the following observation are predicted:

- an important reduction of the annual rainfall pattern (-42.0 mm/year), with alternative variations (increasing or decreasing) at monthly scale, with the higher reductions predicted during February and October;
- a slight increase (+67.6 mm/year) of annual reference evapotranspiration, especially during spring-summer months (with values up to +10.9 mm/month in July), and with a “peak” of daily evapotranspiration in July (5.7 mm/day);

Tab. 109 – Monthly and annual average values of predicted rainfall and evapotranspiration under present and future climate conditions in Syros Island (Greece).

Month	Rain			ETo		
	2000	2050	var. (mm)	2000	2050	var. (mm)
1	35.9	50.3	14.4	67.1	69.7	2.6
2	49.6	25.0	-24.6	63.8	67.2	3.4
3	31.5	23.4	-8.1	80.0	86.3	6.3
4	9.9	9.0	-1.0	91.6	97.1	5.5
5	6.7	3.5	-3.2	118.1	125.5	7.4
6	0.0	2.8	2.8	144.2	152.7	8.5
7	3.5	1.6	-1.8	166.6	177.5	10.9
8	7.1	2.6	-4.5	162.4	170.3	7.9
9	13.3	18.4	5.1	130.7	135.4	4.7
10	52.4	20.4	-32.0	98.5	102.3	3.8
11	32.5	37.7	5.2	75.9	78.9	2.9
12	54.5	60.3	5.7	70.4	74.0	3.6
Total	296.9	255.0	-42.0	1269.4	1337.0	67.6

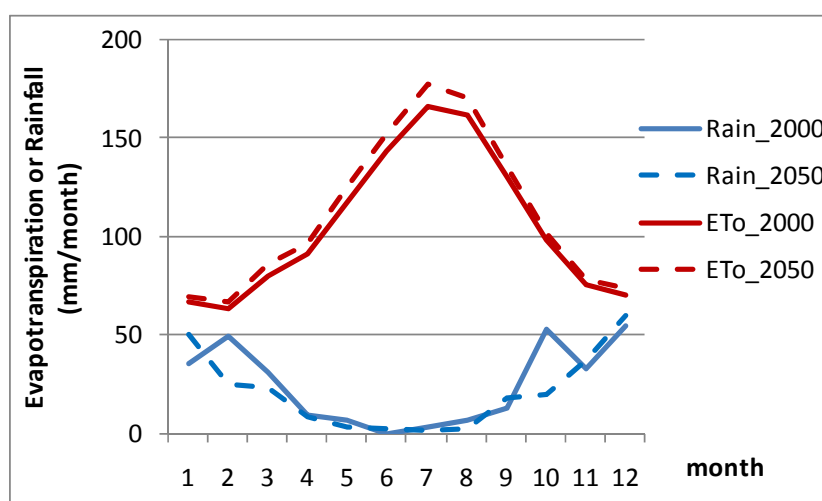


Fig. 87 – Monthly trends of predicted rainfall and evapotranspiration under present and future climate conditions in Syros Island (Greece).

- an important increase in annual average mean air temperatures, up to +1.3°C;
- a relatively uniform increase in monthly average air temperature, with values ranging from +1.1 to 1.4°C/month;
- an increase in the “peak” air temperature during the hotter month of August, with average mean value projected to reach 25.0°C.

Tab. 110 – Monthly and annual average values and relative variations of predicted maximum, minimum and average air temperature under present and future climate conditions in Syros Island (Greece).

Month	Tmean		
	2000	2050	var. (°C)
1	12.1	13.4	1.3
2	12.0	13.2	1.2
3	12.9	14.1	1.2
4	14.8	15.9	1.1
5	17.8	19.0	1.2
6	21.2	22.6	1.4
7	23.5	24.9	1.4
8	23.7	25.0	1.4
9	21.6	23.0	1.4
10	18.9	20.1	1.2
11	16.0	17.2	1.2
12	13.2	14.6	1.4
Average	17.3	18.6	1.3

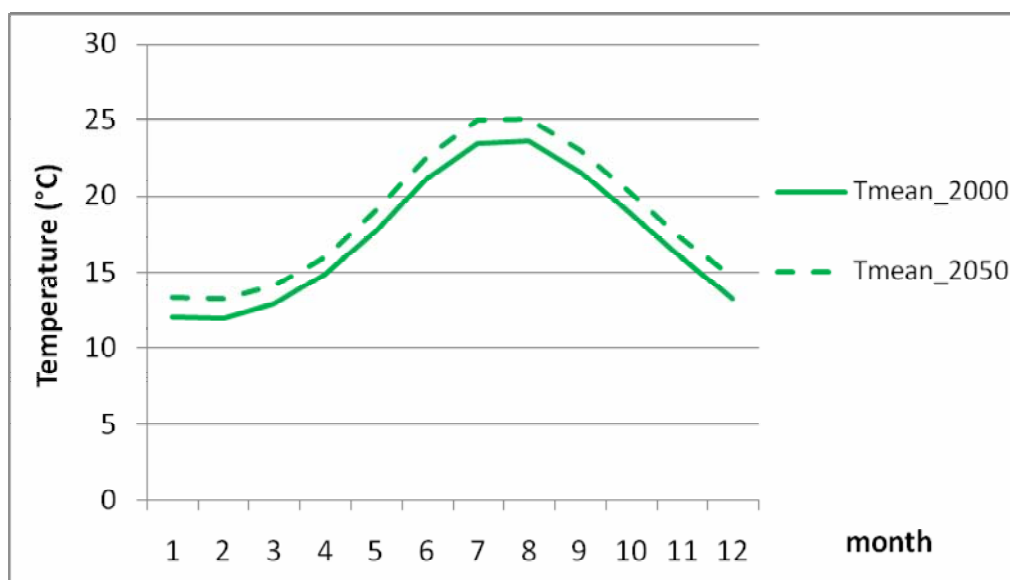


Fig. 88 – Monthly trends of predicted maximum, minimum and mean air temperatures under present and future climate conditions Syros Island (Greece).

6.2. Wheat

6.2.1. Cycle length and crop coefficient curves

The effect of temperature increase (and relative GDD accumulation) on current and projected crop cycle length and corresponding crop coefficient curves is represented in the following graphs, and the following observations have to be highlighted:

- if varietal adaptation is not considered, an important reduction of the total growing cycle is predicted for all planting dates, because of the faster accumulation of the required GGD sum under “future” climate conditions (2050) (fig. 89-90);
- on the contrary, if a late maturing variety will be used, the total crop cycle length (2050 late_var) is projected to remain relatively the same as for the current variety under “present” climate conditions (2000) (fig. 90);
- with respect to the four crop coefficient stages, a relative reduction is predicted in proportion to the corresponding increase in the cumulative GDD (lower during winter, higher during spring-summer months), both in the case of early (November) and late (February) sowing dates (fig. 89).

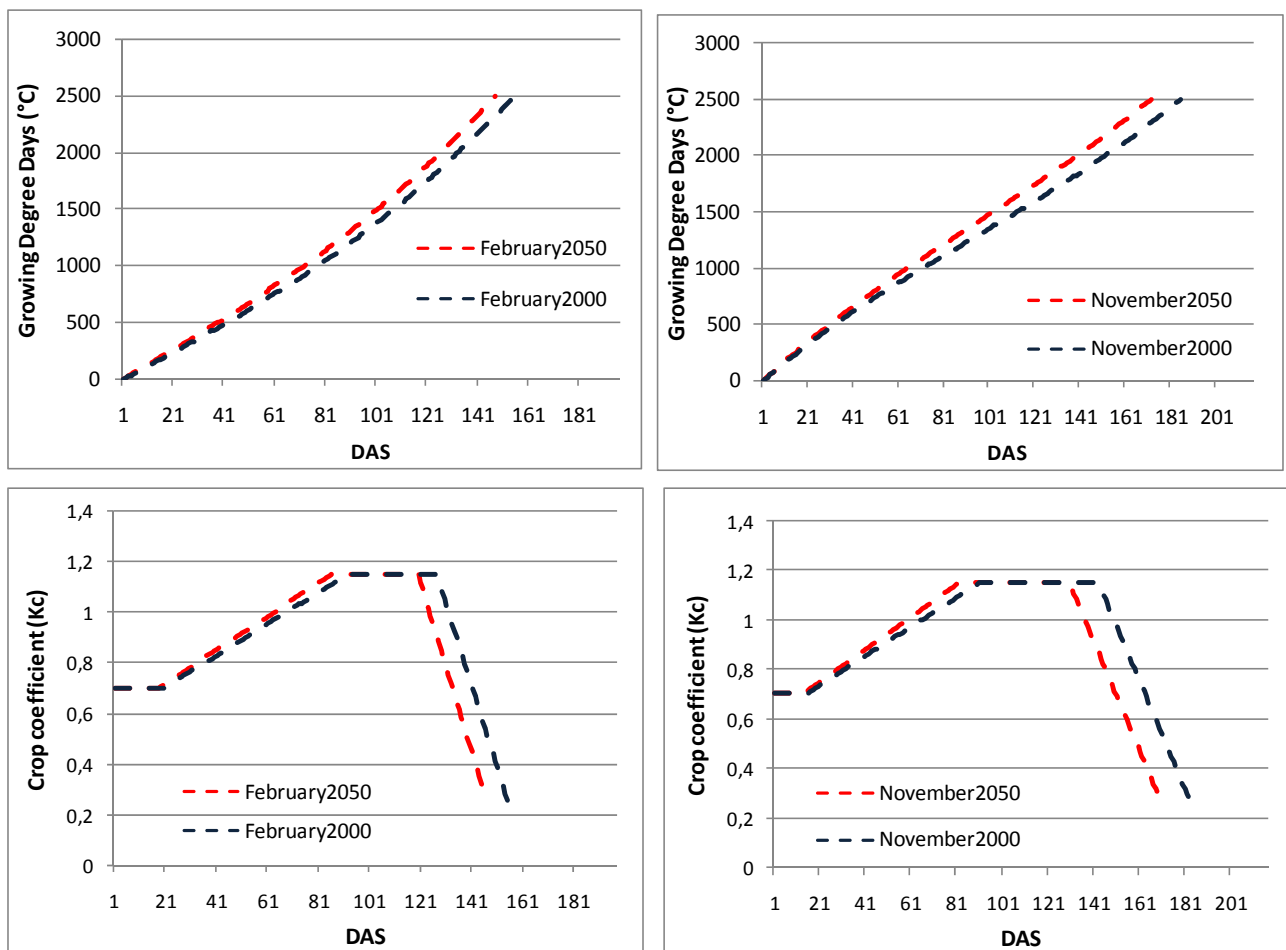


Fig. 89 – Predicted cumulative GDD and corresponding Kc curves for wheat in Syros Island (Greece) as affected by different planting dates and climate scenarios.

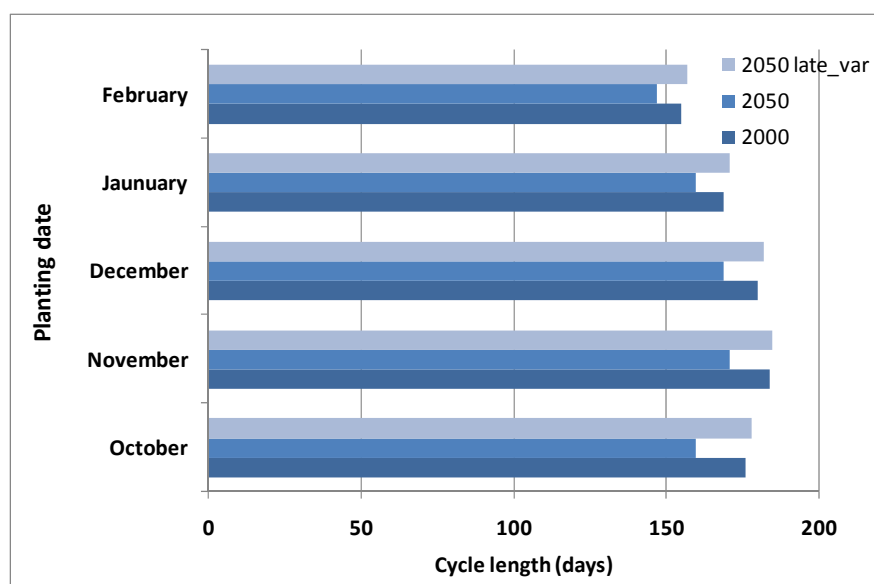


Fig. 90 – Length of total growing cycle of wheat in Syros Island (Greece) as affected by planting date, variety selection and climate variations.

6.2.2. Crop evapotranspiration and irrigation requirements

The impact of climate change on maximum and effective crop evapotranspiration as well as on net irrigation requirements, also considering the relative effect of selected adaptation strategies (planting dates, variety selection and deficit irrigation strategies), is summarized in the following tables and graphs. In brief, the following observations are reported:

- maximum seasonal crop evapotranspiration is projected to reduce for the current variety under “future” (2050) scenario as a consequence of the expected shortening of the crop growing cycle, on average of about -3.9% with respect to current conditions (2000) (fig. 92 and tab.111);
- on the contrary, if a late maturing variety (2050 late_var) is selected, maximum evapotranspiration is projected to increase (on average of about +7.4%) for all the planting dates (fig. 92 and tab.111);
- the relative effect of the projected variation of rainfall patterns seems to be relevant for the crop water balance, with reduction of about 20 mm (about -15%) during the cropping cycle (tab.112);
- maximum seasonal crop evapotranspiration is observed always to increase (in absolute terms) for late (February) planting date with respect to earlier (October) ones, because of the shifting of most of the cycle towards the spring-summer season (fig. 92 and tab.111);
- effective seasonal crop evapotranspiration and net irrigation requirements are both highly dependent on the irrigation strategy, progressively reducing going from full irrigation to rainfed conditions (fig. 92 and tab.113-114);
- as for ET_{c_max} , also the ET_{c_eff} and NIR are projected to decrease in 2050 if the current variety is used; on the other side, if a late maturing variety is selected, NIR is clearly projected to increase, while ET_{c_eff} variation is more dependent on the irrigation strategy considered (fig. 92 and tab.113-114);

Tab. 111 – Effect of planting date and variety selection on the maximum crop evapotranspiration of wheat in Syros Island (Greece) under “present” and “future” climate conditions.

Planting date	ETc_max 2000	ETc_max 2050		ETc_max 2050 late_var	
	[mm/season]	[mm/season]	(variation vs 2000)	[mm/season]	(variation vs 2000)
october	389.4	368.8	-5.3%	411.2	5.6%
november	409.9	390.3	-4.8%	436.3	6.5%
december	433.5	416.7	-3.9%	467.1	7.8%
january	431.4	416.3	-3.5%	467.3	8.3%
february	472.8	462.1	-2.3%	514.1	8.7%
average	427.4	410.8	-3.9%	459.2	7.4%

Tab. 112 – Effect of planting date and variety selection on the effective rainfall pattern during crop cycle of wheat in Syros Island (Greece) under “present” and “future” climate conditions.

Planting date	Rain_eff 2000	Rain_eff 2050		Rain_eff 2050 late_var	
	[mm/season]	[mm/season]	(variation vs 2000)	[mm/season]	(variation vs 2000)
october	195.9	155.7	-20.5%	169.5	-13.5%
november	171.2	155.7	-9.1%	158.5	-7.4%
december	150.5	137.1	-8.9%	137.1	-8.9%
january	83.8	65.2	-22.2%	65.2	-22.2%
february	78.1	50.2	-35.7%	50.2	-35.7%
average	135.9	112.8	-17.0%	116.1	-14.6%

Tab. 113 – Effect of irrigation strategies and variety selection on the effective evapotranspiration of wheat in Syros Island (Greece) under “present” and “future” climate conditions.

Irrigation strategy	ETc_eff 2000	ETc_eff 2050		ETc_eff 2050 late_var	
	[mm/season]	[mm/season]	(variation vs 2000)	[mm/season]	(variation vs 2000)
full	427.4	410.8	-3.9%	459.2	7.4%
mild1	419.1	394.7	-5.8%	440.0	5.0%
mild2	406.9	389.0	-4.4%	430.5	5.8%
medium	389.4	339.3	-12.9%	373.9	-4.0%
severe1	362.9	339.7	-6.4%	371.2	2.3%
severe2	316.6	281.6	-11.1%	302.4	-4.5%
rainfed	240.7	221.5	-8.0%	226.8	-5.8%

Tab. 114 – Effect of irrigation strategies and variety selection on the net irrigation requirements of wheat in Syros Island (Greece) under “present” and “future” climate conditions.

Irrigation strategy	NIR 2000	NIR 2050		NIR 2050 late_var	
	[mm/season]	[mm/season]	(variation vs 2000)	[mm/season]	(variation vs 2000)
full	263.2	260.3	-1.1%	308.5	17.2%
mild1	234.7	219.0	-6.7%	270.1	15.1%
mild2	210.5	208.2	-1.1%	246.8	17.2%
medium	173.0	148.6	-14.1%	198.2	14.6%
severe1	152.6	142.4	-6.7%	175.6	15.1%
severe2	86.5	74.3	-14.1%	99.1	14.6%
rainfed	0.0	0.0	0.0%	0.0	0.0%

- by plotting together the values of seasonal ETc_{eff} and NIR (obtained under different irrigation strategies and variety) for different climate scenarios, there is a clear prediction of their reduction (respectively of about -7.1% and -5.3%, on average) while, by considering a late maturing variety, an increase of both is predicted (respectively of about +2.2% and +13.2%, on average) (fig. 91);
- the cumulative curves of ETc_{max} in 2050 (versus 2000) show always (also under different planting dates) a clear shifting towards higher values, thus representing the relative increase in the daily crop water requirements, although with a decrease in the cumulative final value (depending on the anticipated ending of the cycle) (fig. 93).

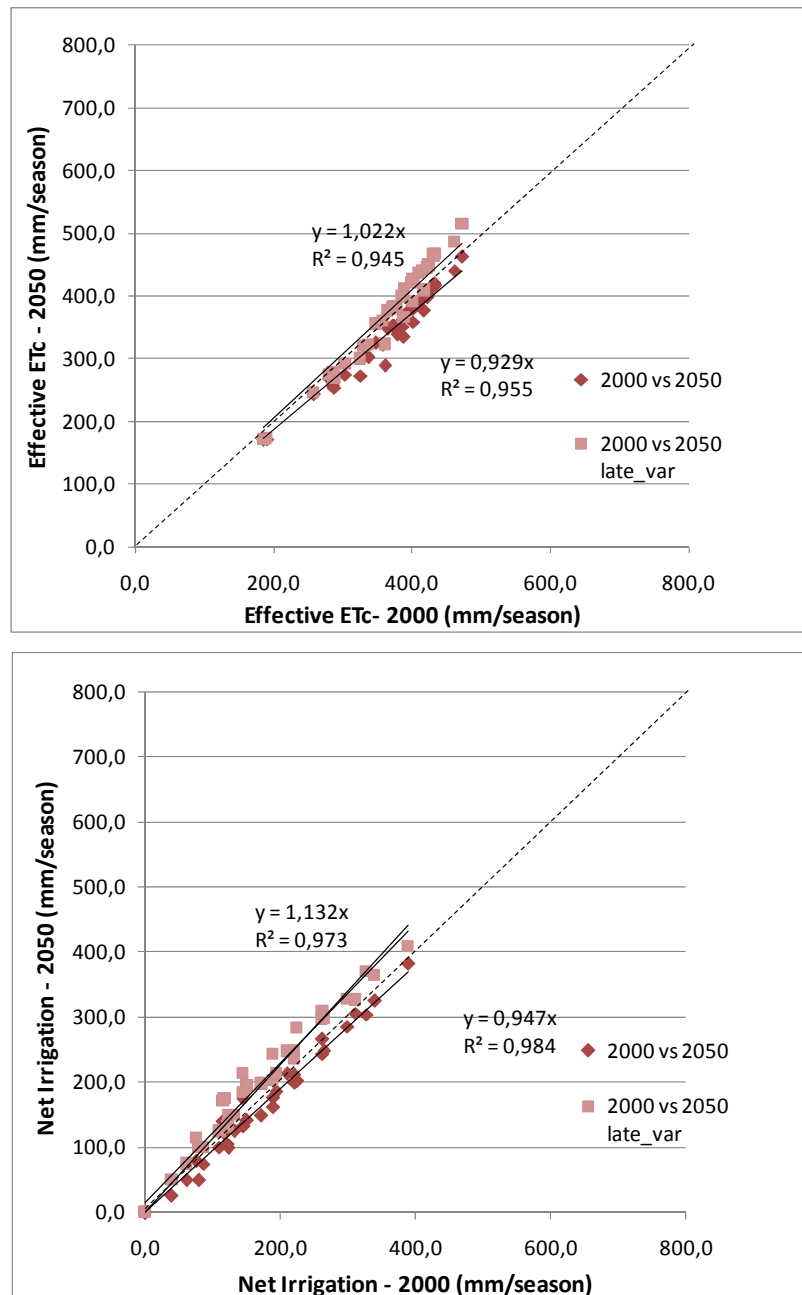


Fig. 91 – Scatter-plot of seasonal crop evapotranspiration and net irrigation requirements of as affected by different variety selection for wheat in Syros Island (Greece) under “present” and “future” climate conditions.

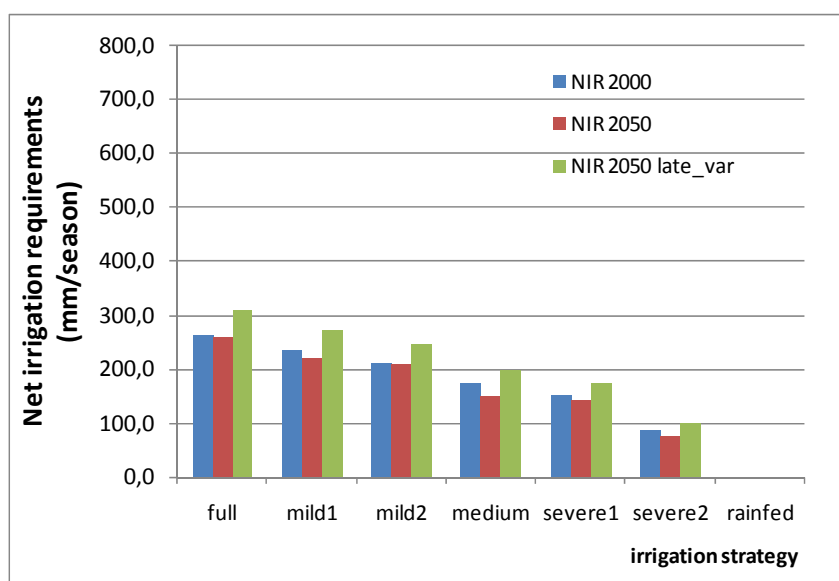
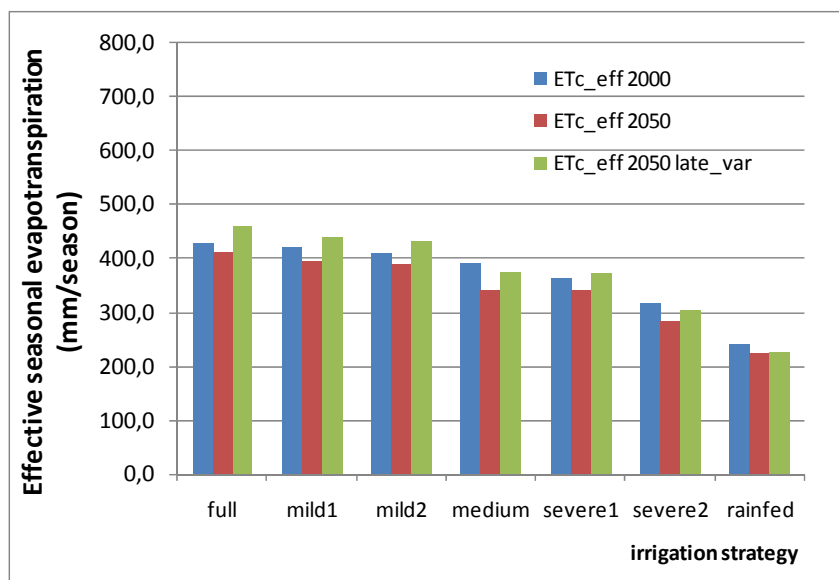
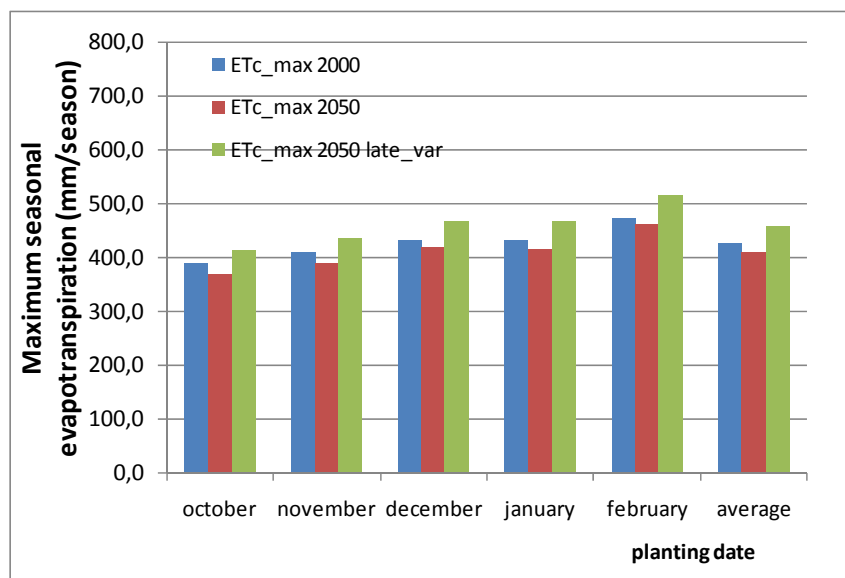


Fig. 92 – Effect of planting date, irrigation strategies and variety selection on maximum and effective crop evapotranspiration and net irrigation requirements of wheat in Syros Island (Greece) under “present” and “future” climate conditions.

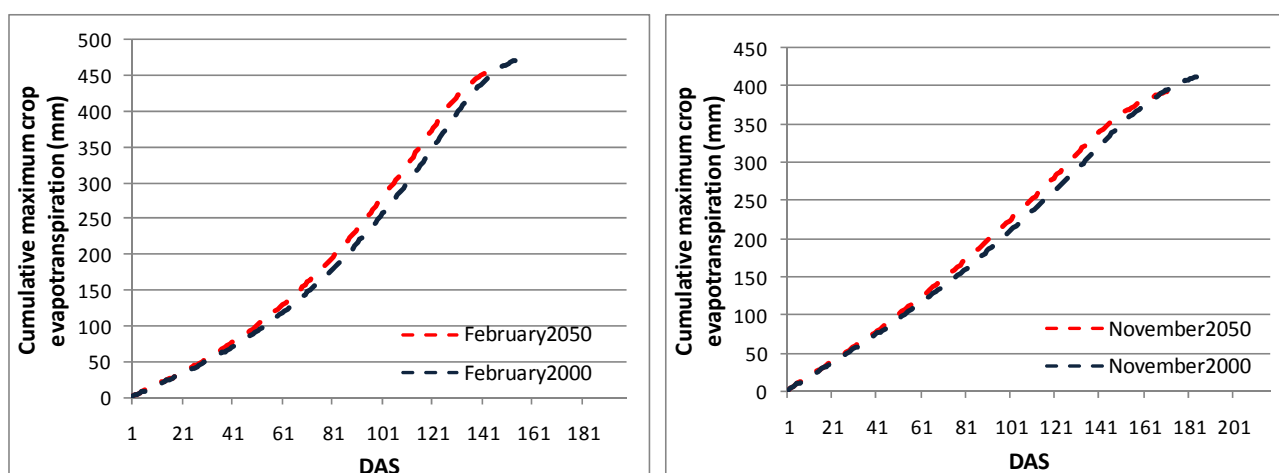


Fig. 93 – Cumulative curves of maximum crop evapotranspiration as affected by different planting date for wheat in Syros Island (Greece) under “present” and “future” climate conditions.

6.2.3. Crop evapotranspiration under extreme weather conditions.

If a simulated future “extreme weather” climate condition (2050+1) is considered (created by adding +1°C to daily temperature of 2050 climate scenario), the following observations on crop cycle length are reported (fig.94):

- with current variety, a further important reduction of the total growing cycle is predicted for quite all planting dates with respect to 2000 and 2050 scenario, because of the further faster accumulation of the required GDD sum;
- if a late maturing variety is considered, the total crop cycle length (2050+1 late_var) is only partly recovered with respect to present (2000) scenario only, while it is significantly shortened in all other cases with respect to 2050 late_var and 2000 scenarios.

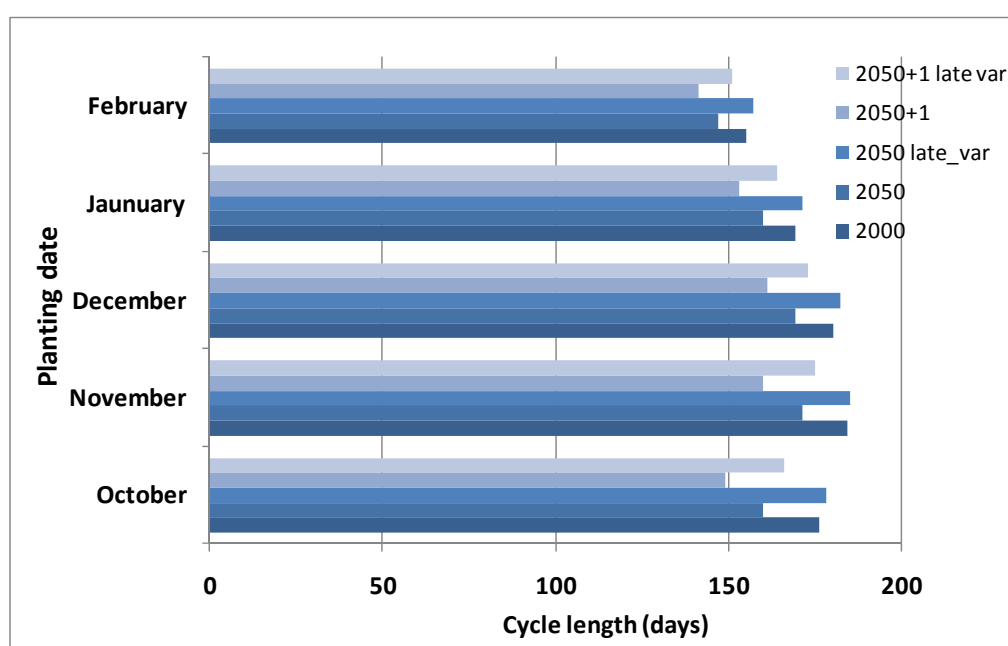


Fig. 94 – Length of total growing cycle of wheat in Syros Island (Greece) as affected by planting date and variety selection under “present (2000)”, “future (2050)” and “future extreme weather (2050+1)” climate conditions.

The impact of future “extreme weather” conditions (2050+1) on maximum and effective crop evapotranspiration as well as on net irrigation requirements, also considering the relative effect of selected adaptation strategies (planting dates, variety selection and deficit irrigation strategies), is summarized in the following tables and graphs. In brief, the following observations are reported:

- *ETc_max* is projected to reduce for the current variety under future “extreme weather” (2050+1) scenario as a consequence of the expected further shortening of the crop growing cycle, on average of about –6.7% with respect to present conditions (2000); on the contrary, if a late maturing variety (2050+1 late_var) is selected, *ETc_max* is projected to increase (+3.9% on average) (tab.115);
- *ETc_max* is observed always to increase (in absolute terms) for late (February) planting date with respect to earlier (October) ones, because of the shifting of most of the cycle towards the hotter spring-summer season (fig. 95 and tab. 115);
- the relative effect of the projected variation of rainfall patterns (higher than -40%) seems to be relevant for the crop water balance, because of the reduction of about -55mm (tab. 116);
- *ETc_eff* is projected to decrease under 2050+1 scenario if the current variety is used; if a late maturing variety is selected (tab.117), it is projected to decrease (under rainfed and severe conditions) or to increase (under better irrigated conditions), always with respect to 2000 baseline scenario;
- on the other side, *NIR* is projected to increase significantly under 2050+1 scenario, both if the current variety is used or if a late maturing variety is selected (tab.118), always with respect to 2000 baseline scenario;
- *ETc_eff* and *NIR* are both highly dependent on the irrigation strategy, progressively reducing especially from medium stress to rainfed conditions, under all climate scenarios (fig.95);
- by plotting together the values of seasonal *ETc_eff* and *NIR* for 2000 versus 2050+1 climate scenarios, there is a clear prediction of *ETc_eff* reduction with both current and late varieties (respectively of about -9.7% and -1.2%, on average), but, on the other side, an correspondent increase of *NIR* (respectively of about +4.8% and +20.8%, on average) (fig. 96).

Tab. 115 – Effect of planting date and variety selection on the maximum crop evapotranspiration of wheat in Syros Island (Greece) under “present”, “future” and “future extreme weather” climate conditions.

Planting date	ETc_max 2000	ETc_max 2050		ETc_max 2050 late_var		ETc_max 2050+1		ETc_max 2050+1 late_var	
	(mm)	(mm)	var.% (2000)	(mm)	var.% (2000)	(mm)	var.% (2000)	(mm)	var.% (2000)
october	389.4	368.8	-5.3%	411.2	5.6%	358.5	-7.9%	398.7	2.4%
november	409.9	390.3	-4.8%	436.3	6.5%	376.3	-8.2%	420.9	2.7%
december	433.5	416.7	-3.9%	467.1	7.8%	404.2	-6.7%	449.1	3.6%
january	431.4	416.3	-3.5%	467.3	8.3%	403.5	-6.5%	451.5	4.7%
february	472.8	462.1	-2.3%	514.1	8.7%	451.1	-4.6%	500.9	5.9%
average	427.4	410.8	-3.9%	459.2	7.4%	398.7	-6.7%	444.2	3.9%

Tab. 116 – Effect of planting date and variety selection on the effective rainfall pattern during crop cycle of wheat in Syros Island (Greece) under “present”, “future” and “future extreme weather” climate conditions.

Planting date	Rain_eff 2000	Rain_eff 2050		Rain_eff 2050 late_var		Rain_eff 2050+1		Rain_eff 2050+1 late_var	
	(mm)	[mm/season]	var.% (2000)	(mm)	var.% (2000)	(mm)	var.% (2000)	(mm)	var.% (2000)
october	195.9	155.7	-20.5%	169.5	-13.5%	105.5	-46.1%	112.5	-42.6%
november	171.2	155.7	-9.1%	158.5	-7.4%	109.0	-36.3%	110.9	-35.2%
december	150.5	137.1	-8.9%	137.1	-8.9%	96.0	-36.2%	96.0	-36.2%
january	83.8	65.2	-22.2%	65.2	-22.2%	44.6	-46.8%	45.7	-45.5%
february	78.1	50.2	-35.7%	50.2	-35.7%	35.2	-55.0%	35.2	-55.0%
average	135.9	112.8	-17.0%	116.1	-14.6%	78.0	-42.6%	80.0	-41.1%

Tab. 117 – Effect of irrigation strategies and variety selection on the effective crop evapotranspiration of wheat in Syros Island (Greece) under “present”, “future” and “future extreme weather” climate conditions.

Irrigation strategy	ETc_eff 2000	ETc_eff 2050		ETc_eff 2050 late_var		ETc_eff 2050+1		ETc_eff 2050+1 late_var	
	(mm)	(mm)	var.% (2000)	(mm)	var.% (2000)	(mm)	var.% (2000)	(mm)	var.% (2000)
full	427.4	410.8	-3.9%	459.2	7.4%	398.7	-6.7%	444.2	3.9%
mild1	419.1	394.7	-5.8%	440.0	5.0%	388.1	-7.4%	430.6	2.8%
mild2	406.9	389.0	-4.4%	430.5	5.8%	374.7	-7.9%	411.8	1.2%
medium	389.4	339.3	-12.9%	373.9	-4.0%	352.0	-9.6%	383.9	-1.4%
severe1	362.9	339.7	-6.4%	371.2	2.3%	324.7	-10.5%	353.6	-2.5%
severe2	316.6	281.6	-11.1%	302.4	-4.5%	272.6	-13.9%	290.2	-8.3%
rainfed	240.7	221.5	-8.0%	226.8	-5.8%	189.1	-21.4%	193.1	-19.8%

Tab. 118 – Effect of irrigation strategies and variety selection on the net irrigation requirements of wheat in Syros Island (Greece) under “present”, “future” and “future extreme weather” climate conditions.

Irrigation strategy	NIR 2000	NIR 2050		NIR 2050 late_var		NIR 2050+1		NIR 2050+1 late_var	
	(mm)	(mm)	var.% (2000)	(mm)	var.% (2000)	(mm)	var.% (2000)	(mm)	var.% (2000)
full	263.2	260.3	-1.1%	308.5	17.2%	281.8	7.1%	329.4	25.2%
mild1	234.7	219.0	-6.7%	270.1	15.1%	256.0	9.1%	292.6	24.7%
mild2	210.5	208.2	-1.1%	246.8	17.2%	225.4	7.1%	263.5	25.2%
medium	173.0	148.6	-14.1%	198.2	14.6%	203.5	17.7%	221.3	27.9%
severe1	152.6	142.4	-6.7%	175.6	15.1%	166.4	9.1%	190.2	24.7%
severe2	86.5	74.3	-14.1%	99.1	14.6%	101.8	17.7%	110.7	27.9%
rainfed	0.0	0.0		0.0		0.0		0.0	

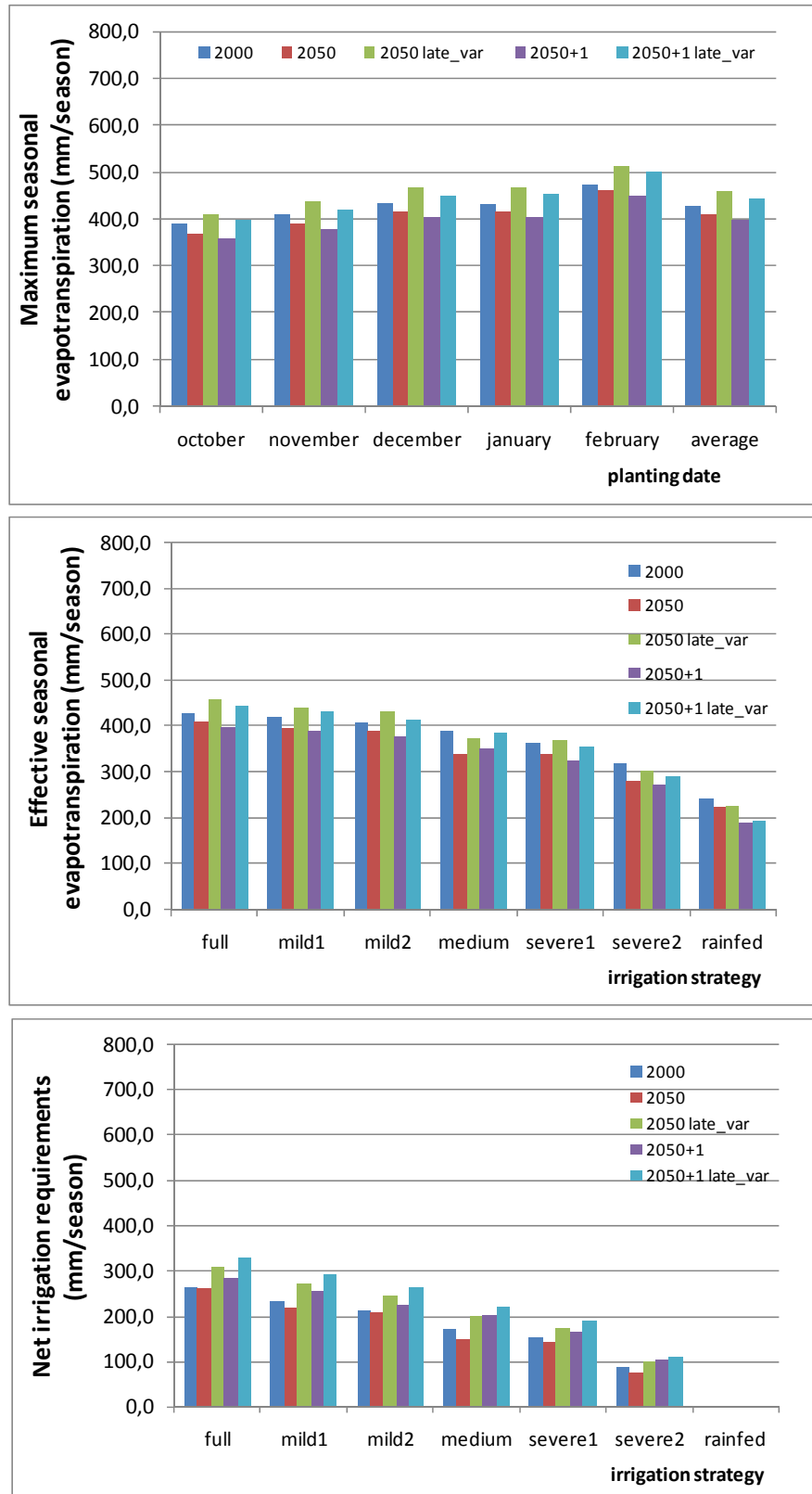


Fig. 95 – Effect of planting date, irrigation strategies and variety selection on maximum and effective crop evapotranspiration and net irrigation requirements of wheat in Syros Island (Greece) under “present” and “future” and “extreme weather (2050+1)” climate conditions.

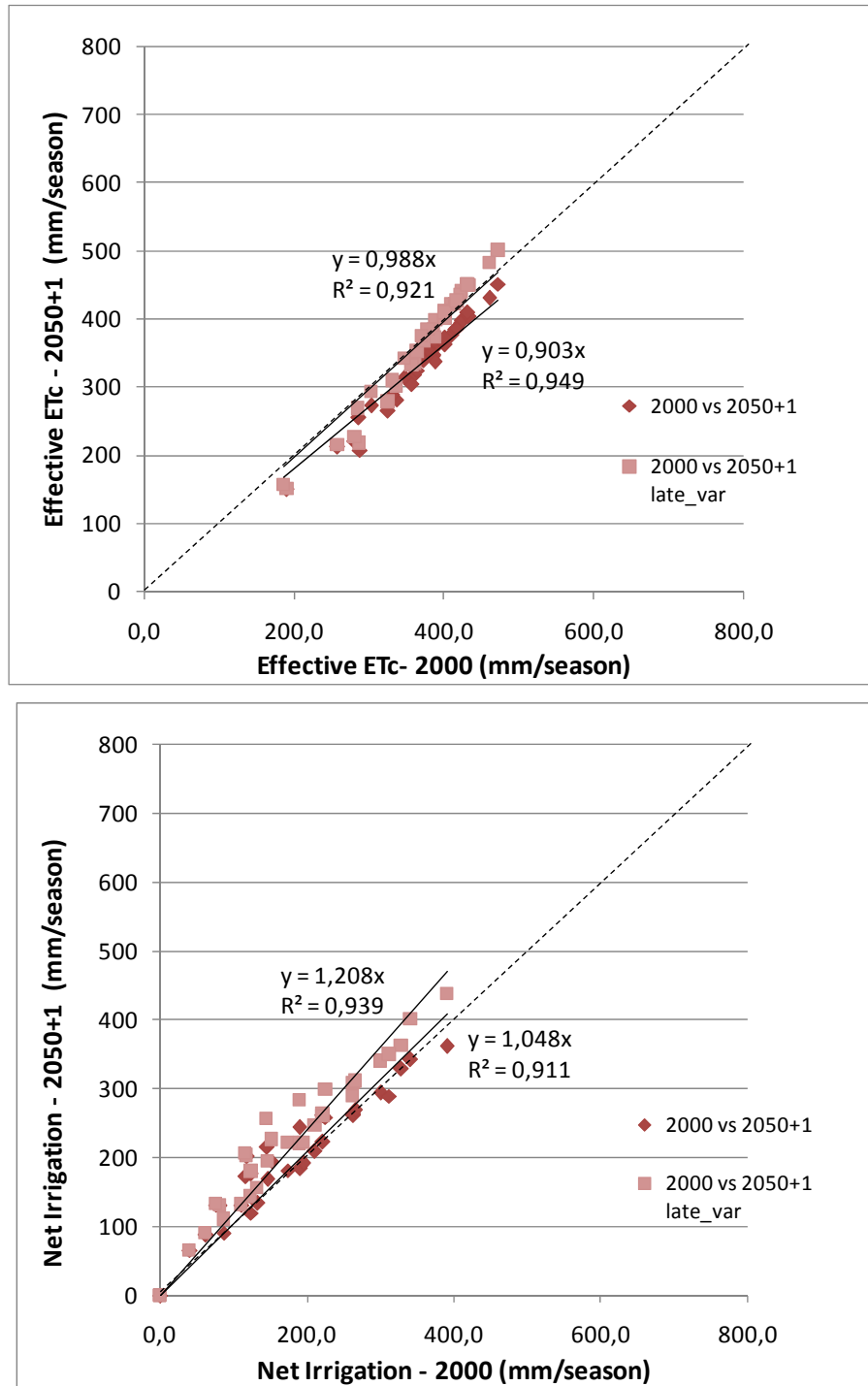


Fig. 96 – Scatter-plot of seasonal crop evapotranspiration and net irrigation requirements of as affected by different variety selection for wheat in Syros Island (Greece) under “present (2000)” and “future extreme weather (2050+1)” climate conditions.

6.2.4. Yield response to water

The impact of “future” climate projections (2050) and “extreme weather” (2050+1) on potential yield, also considering the relative effect of selected adaptation strategies (planting dates, variety selection and deficit irrigation strategies), is summarized in the following tables and graphs. In brief, the following observations are reported:

- potential yield is projected to reduce under “future” scenario (2050) with respect to current conditions (2000), on average from 4.7 to 4.5 t ha⁻¹ (about -3.9%), depending on irrigation strategies (tab. 119 and fig.97) and planting dates (tab. 120 and fig.97) as a consequence of the expected shortening of the crop growing cycle;
- on the contrary, if the expected fertilizing effect due to an increase in atmospheric CO₂ concentration will occur, yield is projected to increase in quite all conditions (2050 wp_adj), up to an average of 5.4 t ha⁻¹ (+15.4%), and thus to overcome the effect of the shortening of the crop cycle (fig. 97 and tab.119-120);
- on the other side, if a late maturing variety (2050 late_var) is selected, yield is projected to increase up to an average of 5.1 t ha⁻¹ (+7.3%), especially under fully irrigation (fig.97 and tab.119-120);
- if “extreme weather” conditions (2050+1) are considered, the average expected yield reduction (down to 4.4 t ha⁻¹, -6.7%) is greater than in 2050 scenario, but also in this case it could be completely recovered because of the CO₂ fertilizing effect or the late-variety selection, respectively to 5.3 t ha⁻¹ (+12%) and 4.9 t ha⁻¹ (+3.9%);
- with respect to irrigation strategies, there is a clear reduction in potential yield under increasing water stress conditions (fig.97), but still under “severe” water stress (thus only supported by supplemental irrigations) values up to 2.5-4 t ha⁻¹ are expected, while under rainfed conditions, an average yield of 1.5-2 t ha⁻¹ is still predicted in all climate conditions;
- yield is observed always to increase (in absolute terms) for late (February) planting date with respect to earlier (October) ones (fig.97), but a corresponding increase in crop water requirements is clearly projected (as it has been highlighted in the previous paragraph).

Tab. 119 – Effect of irrigation strategies, variety selection and atmospheric CO₂ increase on the potential yield of wheat in Syros Island (Greece) under “present”, “future” and “extreme weather” climate conditions.

Irrigation strategy	Yield 2000 (*)	Yield 2050 (*)		Yield 2050 wp_adj (**)		Yield 2050 late_var (*)		Yield 2050+1 (*)		Yield 2050+1 wp_adj (**)		Yield 2050+1 late_var (*)	
		(t/ha)	var.% (2000)	(t/ha)	var.% (2000)	(t/ha)	var.% (2000)	(t/ha)	var.% (2000)	(t/ha)	var.% (2000)	(t/ha)	var.% (2000)
full	4.7	4.5	-3.9%	5.4	15.4%	5.1	7.4%	4.4	-6.7%	5.3	12.0%	4.9	3.9%
mild1	4.6	4.3	-6.9%	5.1	11.7%	4.7	3.5%	4.2	-7.5%	5.1	11.0%	4.7	2.5%
mild2	4.4	4.2	-4.6%	5.0	14.5%	4.6	5.0%	4.0	-8.6%	4.8	9.6%	4.3	-0.3%
medium	4.1	3.4	-17.9%	4.1	-1.5%	3.7	-9.7%	3.7	-10.3%	4.4	7.7%	4.0	-2.6%
severe1	3.7	3.4	-7.4%	4.1	11.1%	3.7	0.1%	3.2	-11.8%	3.9	5.9%	3.5	-4.3%
severe2	3.0	2.6	-13.9%	3.1	3.3%	2.8	-8.4%	2.6	-15.3%	3.1	1.7%	2.7	-10.2%
rainfed	2.1	1.9	-6.8%	2.3	11.8%	2.0	-5.5%	1.6	-22.9%	1.9	-7.5%	1.6	-20.9%
(*) assuming wp (2000) = 1.1 (kg/m3)													
(**) assuming wp (2050)= wp(2000)*1.2= 1.32 (kg/m3)													

Tab. 120 – Effect of planting date, variety selection and atmospheric CO₂ increase on the potential yield of wheat in Syros Island (Greece) under “present”, “future” and “extreme weather” climate conditions.

Irrigation strategy	Yield 2000 (*)	Yield 2050 (*)		Yield 2050 wp_adj (**)		Yield 2050 late_var (*)		Yield 2050+1 (*)		Yield 2050+1 wp_adj (**)		Yield 2050+1 late_var (*)	
		(t/ha)	var.% (2000)	(t/ha)	var.% (2000)	(t/ha)	var.% (2000)	(t/ha)	var.% (2000)	(t/ha)	var.% (2000)	(t/ha)	var.% (2000)
october	4.3	4.1	-5.3%	4.9	13.6%	4.5	5.6%	3.9	-7.9%	4.7	10.5%	4.4	2.4%
november	4.5	4.3	-4.8%	5.2	14.3%	4.8	6.5%	4.1	-8.2%	5.0	10.2%	4.6	2.7%
december	4.8	4.6	-3.9%	5.5	15.4%	5.1	7.8%	4.4	-6.7%	5.3	11.9%	4.9	3.6%
january	4.7	4.6	-3.5%	5.5	15.8%	5.1	8.3%	4.4	-6.5%	5.3	12.2%	5.0	4.7%
february	5.2	5.1	-2.3%	6.1	17.3%	5.7	8.7%	5.0	-4.6%	6.0	14.5%	5.5	5.9%
average	4.7	4.5	-3.9%	5.4	15.4%	5.1	7.4%	4.4	-6.7%	5.3	12.0%	4.9	3.9%
(*) assuming wp (2000) = 1.1 (kg/m3)													
(**) assuming wp (2050)= wp(2000)*1.2= 1.32 (kg/m3)													

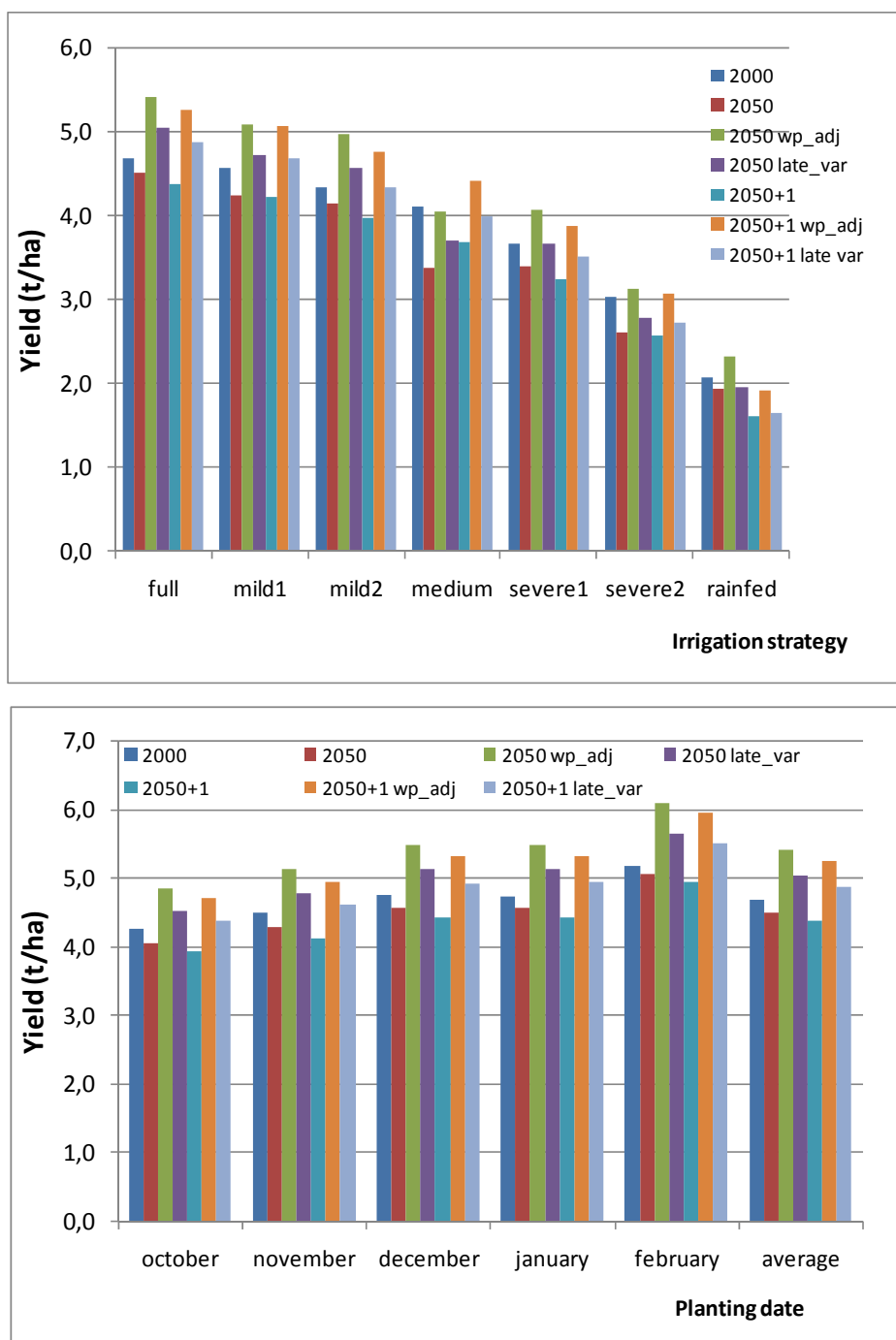


Fig. 97 – Effect of planting date, irrigation strategies, variety selection and atmospheric CO₂ increase on potential yield of wheat in Syros Island (Greece) under “present”, “future” and “extreme weather (2050+1)” climate conditions.

6.3. Tomato

6.3.1. Cycle length and crop coefficient curves

The effect of temperature increase (and relative GDD accumulation) on current and projected crop cycle length and corresponding crop coefficient curves is represented in the following graphs, and the following observations have to be highlighted:

- if varietal adaptation is not considered, an important reduction of the total growing cycle is predicted for all planting dates, because of the faster accumulation of the required GGD sum under “future” climate conditions (2050) (fig. 98-99);
- if a late maturing variety will be used, the total crop cycle length (2050 late_var) is projected to remain relatively the same as for the current variety under “present” climate conditions (2000), especially for late planting dates (fig. 99);
- with respect to the four crop coefficient stages, a relative reduction is predicted in proportion to the corresponding increase in the cumulative GDD (lower during winter, higher during spring-summer months), but with a greater effect in the case of early (March) rather than late (May) planting dates (fig. 98).

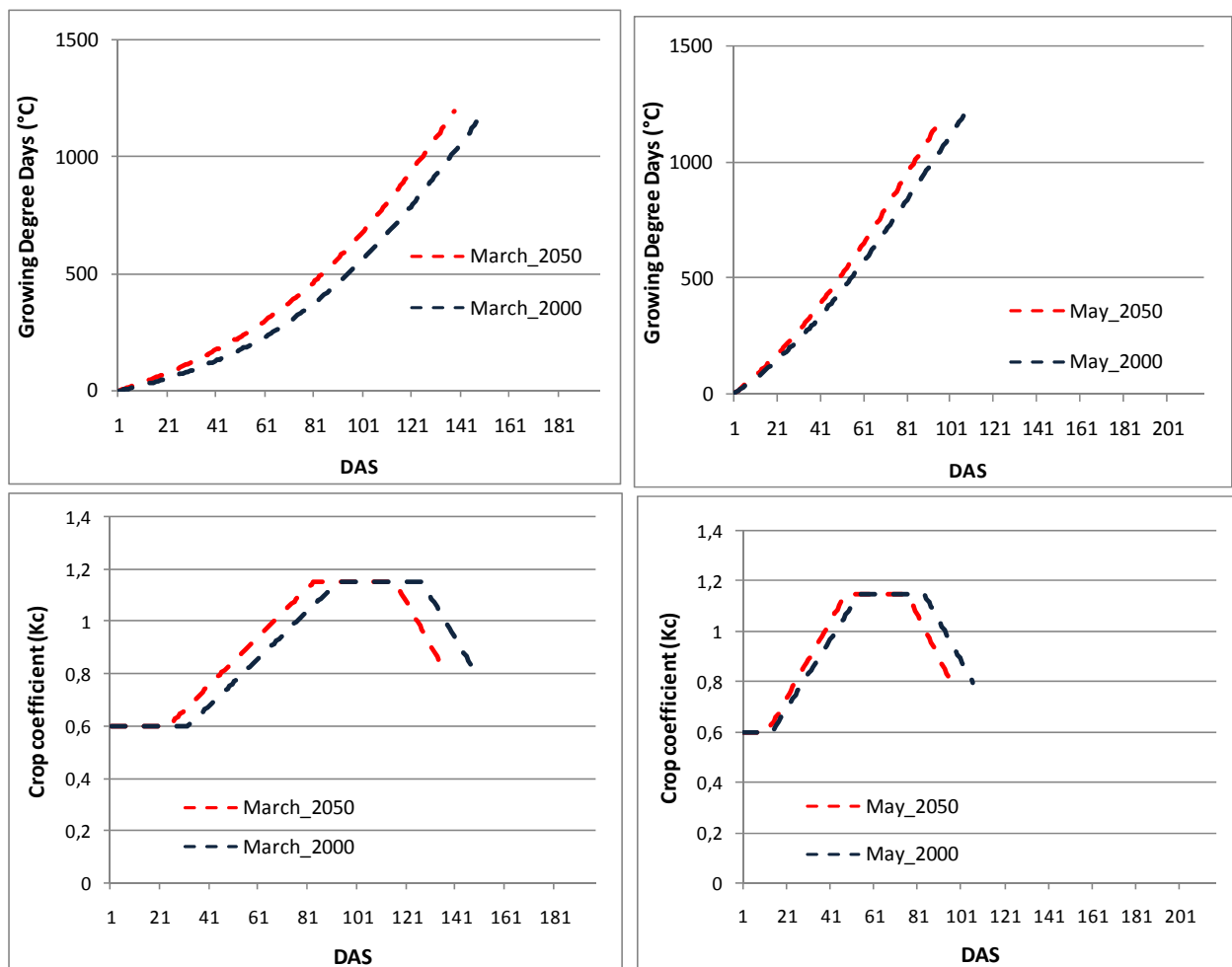


Fig. 98 – Predicted cumulative GDD and corresponding Kc curves for tomato in Syros Island (Greece) as affected by different planting dates and climate scenarios.

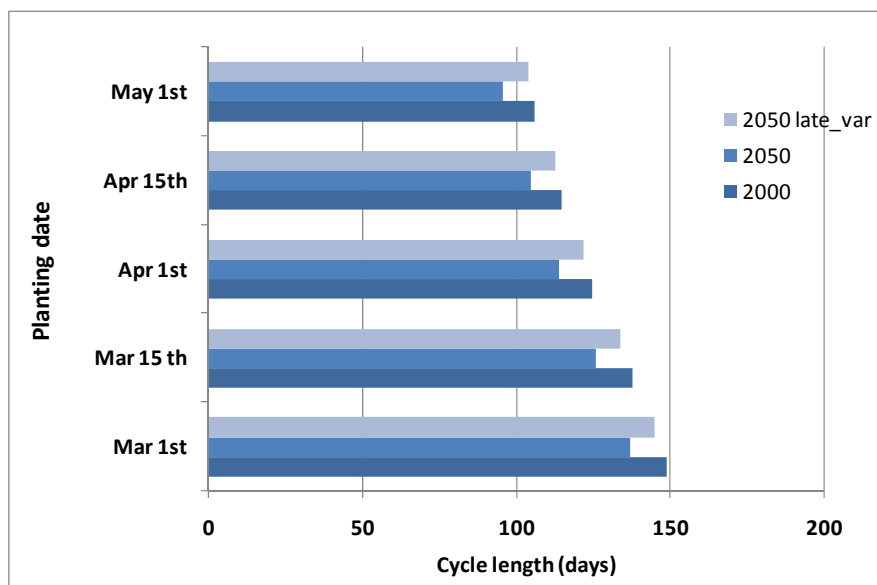


Fig. 99 – Length of total growing cycle of tomato in Syros Island (Greece) as affected by planting date, variety selection and climate variations.

6.3.2. Crop evapotranspiration and irrigation requirements

The impact of climate change on maximum and effective crop evapotranspiration as well as on net irrigation requirements, also considering the relative effect of selected adaptation strategies (planting dates, variety selection and deficit irrigation strategies), is summarized in the following tables and graphs. In brief, the following observations are reported:

- maximum seasonal crop evapotranspiration is projected to reduce for the current variety under “future” (2050) scenario as a consequence of the expected shortening of the crop growing cycle, on average of about -5.1% with respect to current conditions (2000) (fig.101 and tab.121);
- on the contrary, if a late maturing variety (2050 late_var) is selected, maximum evapotranspiration is projected to increase for all the planting dates (on average of about +3.7%) (fig. 101 and tab.121);
- the relative effect of the projected decrease of rainfall patterns seems to be less relevant for the crop water balance, because of their very low values (tab.122);
- maximum seasonal crop evapotranspiration is observed always to decrease slightly (in absolute terms) for late (May) planting date with respect to earlier (March) ones, because of the shifting of the cycle towards the higher summer temperatures and the corresponding reduction in the total length (fig. 101 and tab.121);
- effective seasonal crop evapotranspiration and net irrigation requirements are both highly dependent on the irrigation strategy, progressively reducing going from full irrigation to rainfed conditions (fig. 101 and tab.123-124);
- as for ET_{c_max} , also the ET_{c_eff} and NIR are projected to decrease in 2050 if the current variety is used; on the other side, if a late maturing variety is selected, NIR and ET_{c_eff} are always projected to increase (fig. 101 and tab.123-124);

Tab. 121 – Effect of planting date and variety selection on the maximum crop evapotranspiration of tomato in Syros Island (Greece) under “present” and “future” climate conditions.

Planting date	ETc_max 2000	ETc_max 2050		ETc_max 2050 late_var	
	[mm/season]	[mm/season]	(variation vs 2000)	[mm/season]	(variation vs 2000)
Mar 1st	544.0	517.8	-4.8%	562.0	3.3%
Mar 15 th	529.5	500.9	-5.4%	545.8	3.1%
Apr 1st	511.1	483.3	-5.4%	529.7	3.6%
Apr 15th	496.4	471.9	-4.9%	516.7	4.1%
May 1st	483.9	460.7	-4.8%	504.5	4.3%
average	513.0	486.9	-5.1%	531.7	3.7%

Tab. 122 – Effect of planting date and variety selection on the effective rainfall pattern during crop cycle of tomato in Syros Island (Greece) under “present” and “future” climate conditions.

Planting date	Rain_eff 2000	Rain_eff 2050		Rain_eff 2050 late_var	
	[mm/season]	[mm/season]	(variation vs 2000)	[mm/season]	(variation vs 2000)
Mar 1st	41.3	30.2	-26.7%	31.6	-23.5%
Mar 15 th	30.0	21.6	-28.1%	21.6	-28.1%
Apr 1st	16.1	12.8	-20.3%	12.8	-20.3%
Apr 15th	11.4	8.4	-26.2%	8.4	-26.2%
May 1st	8.1	5.6	-30.7%	5.6	-30.7%
average	21.4	15.7	-26.4%	16.0	-25.2%

Tab. 123 – Effect of irrigation strategies and variety selection on the effective evapotranspiration of tomato in Syros Island (Greece) under “present” and “future” climate conditions.

Irrigation strategy	ETc_eff 2000	ETc_eff 2050		ETc_eff 2050 late_var	
	[mm/season]	[mm/season]	(variation vs 2000)	[mm/season]	(variation vs 2000)
full	513.0	486.9	-5.1%	531.7	3.7%
mild1	496.5	468.1	-5.7%	511.2	3.0%
mild2	452.2	430.3	-4.8%	466.1	3.1%
medium	439.7	407.4	-7.3%	448.7	2.0%
severe1	375.6	354.8	-5.5%	382.8	1.9%
severe2	291.4	272.1	-6.6%	292.9	0.5%
rainfed	141.4	135.4	-4.2%	135.9	-3.9%

Tab. 124 – Effect of irrigation strategies and variety selection on the net irrigation requirements of tomato in Syros Island (Greece) under “present” and “future” climate conditions.

Irrigation strategy	NIR 2000	NIR 2050		NIR 2050 late_var	
	[mm/season]	[mm/season]	(variation vs 2000)	[mm/season]	(variation vs 2000)
full	462.6	441.4	-4.6%	489.8	5.9%
mild1	435.0	408.9	-6.0%	449.4	3.3%
mild2	370.1	353.1	-4.6%	391.8	5.9%
medium	367.7	338.2	-8.0%	370.8	0.8%
severe1	282.7	265.8	-6.0%	292.1	3.3%
severe2	183.9	169.1	-8.0%	185.4	0.8%
rainfed	0.0	0.0	0.0%	0.0	0.0%

- by plotting together the values of seasonal ETc_{eff} and NIR (obtained under different irrigation strategies and variety) for different climate scenarios, there is a clear prediction of their reduction (respectively of about -5.8% and -6.0%, on average) while, by considering a late maturing variety, only a slight increase of both is predicted (respectively of about +2.5% and +3.7%, on average) (fig. 100);
- the cumulative curves of ETc_{max} in 2050 (versus 2000) show always (especially for earlier planting dates) a clear shifting towards higher values, thus representing the relative increase in the daily crop water requirements, although with a decrease in the cumulative final value (depending on the anticipated ending of the cycle) (fig. 102).

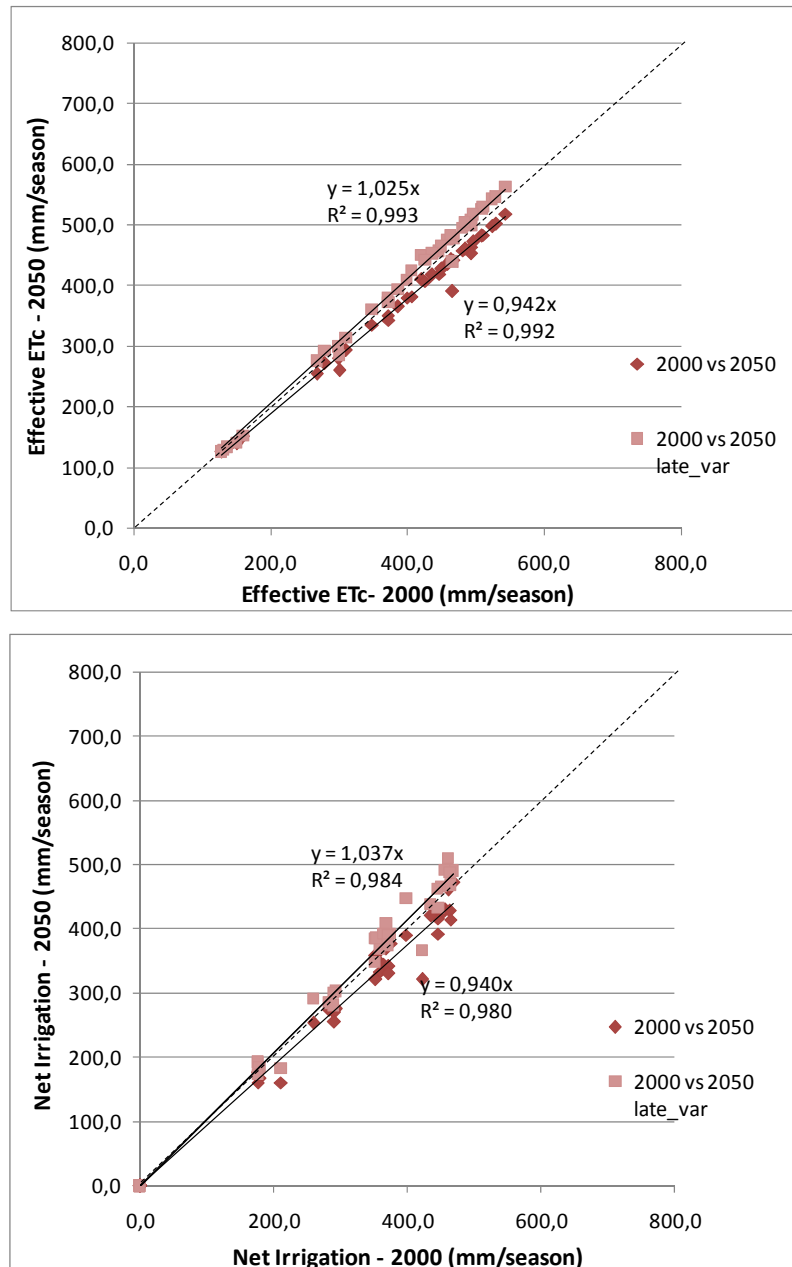


Fig. 100 – Scatter-plot of seasonal crop evapotranspiration and net irrigation requirements of as affected by different variety selection for tomato in Syros Island (Greece) under “present” and “future” climate conditions.

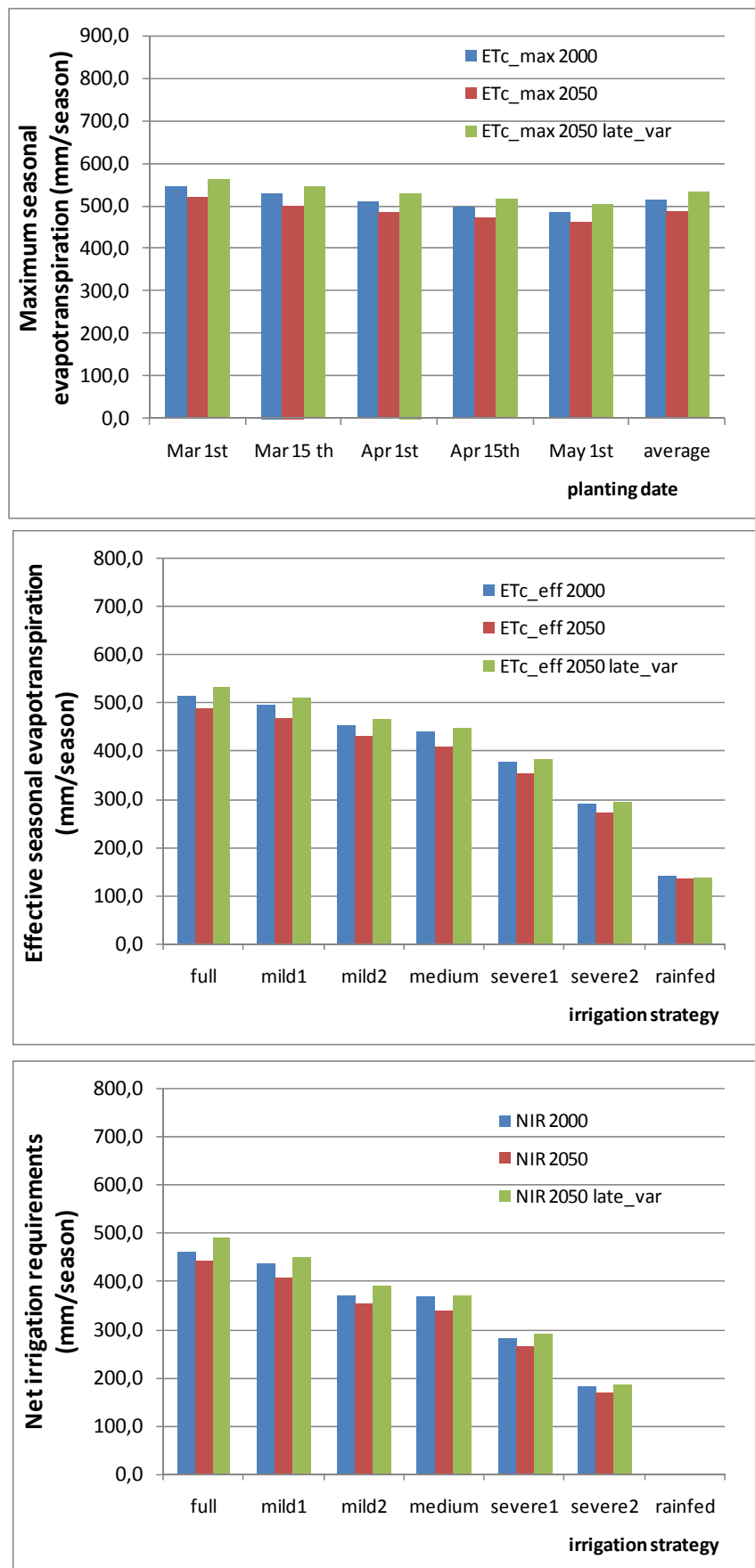


Fig. 101 – Effect of planting date, irrigation strategies and variety selection on maximum and effective crop evapotranspiration and net irrigation requirements of tomato in Syros Island (Greece) under “present” and “future” climate conditions.

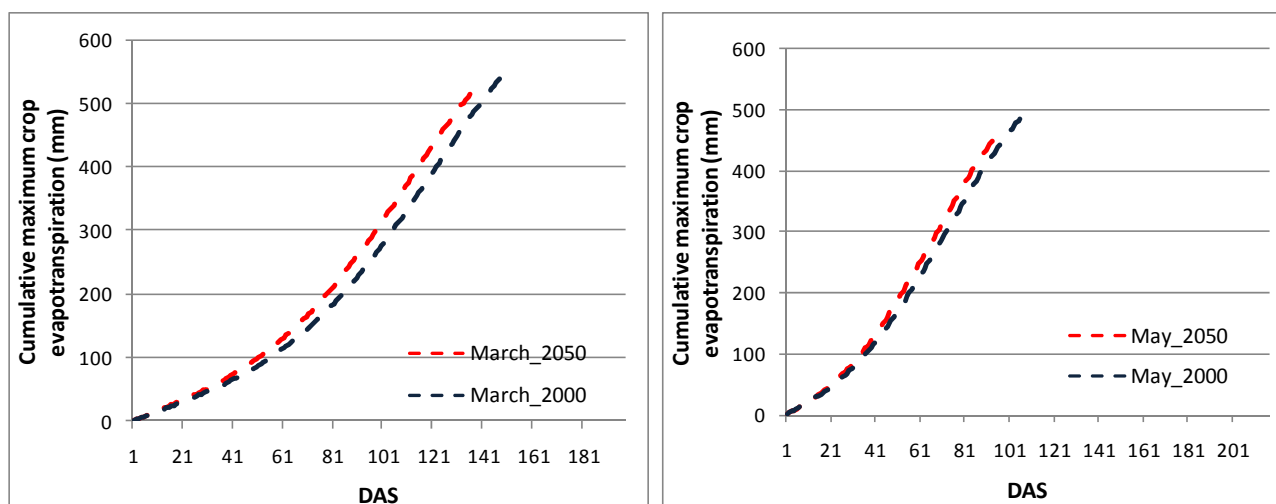


Fig. 102 – Cumulative curves of maximum crop evapotranspiration as affected by different planting date for tomato in Syros Island (Greece) under “present” and “future” climate conditions.

6.3.3. Yield response to water

The impact of climate change on potential yield, also considering the relative effect of selected adaptation strategies (planting dates, variety selection and deficit irrigation strategies), is summarized in the following tables and graphs. In brief, the following observations are reported:

- yield is projected to reduce under “future” scenario (2050) with respect to current conditions (2000), on average from 61.6 to 58.4 t ha⁻¹ (about -5.1%), depending on irrigation strategies (tab. 125 and fig.103) and planting dates (tab. 126 and fig.103) as a consequence of the expected shortening of the crop growing cycle;
- on the contrary, if the expected fertilizing effect due to an increase in atmospheric CO₂ concentration will occur, yield (2050 wp_adj) is projected to increase in quite all conditions (with an average of 70.1 t ha⁻¹, +13.9%), and thus to overcome the effect of the shortening of the crop cycle (fig. 103 and tab.125-126);
- on the other side, if a late maturing variety (2050 late_var) is selected, yield is projected to increase (with an average of 63.8 t ha⁻¹, +3.7%), especially under fully irrigation and late planting dates (fig.103 and tab.125-126);
- there is a clear reduction in potential yield under increasing water stress conditions (fig.103), and under “severe” water stress (thus only supported by supplemental irrigations) values of 15-30 t ha⁻¹ are predicted;
- in the case of rainfed conditions, according to the model used, no yield is expected in all conditions;
- yield is observed always to slightly decrease (in absolute terms) for late (May) planting date with respect to earlier (March) ones (fig.103), because of the shortening of the growing cycle due to its shifting in the hotter summer.

Tab. 125 – Effect of irrigation strategies, variety selection and atmospheric CO₂ increase on the potential yield of tomato in Syros Island (Greece) under “present” and “future” climate conditions.

Irrigation strategy	Yield 2000 (*)	Yield 2050 (*)		Yield 2050 wp_adj (**)		Yield 2050 late_var (*)	
	(t/ha)	(t/ha)	(variation vs 2000)	(t/ha)	(variation vs 2000)	(t/ha)	(variation vs 2000)
full	61.6	58.4	-5.1%	70.1	13.9%	63.8	3.7%
mild1	57.5	53.9	-6.3%	64.6	12.4%	58.8	2.3%
mild2	43.4	41.7	-4.0%	50.0	15.2%	44.7	2.9%
medium	45.1	41.0	-9.2%	49.1	8.9%	45.2	0.1%
severe1	27.9	26.5	-4.8%	31.8	14.2%	28.4	1.8%
severe2	15.2	14.3	-5.9%	17.1	13.0%	15.2	0.1%
rainfed	0.0	0.0		0.0		0.0	
(*) assuming wp (2000) = 12 (kg/m3)							
(**) assuming wp (2050)= wp(2000)*1.2= 14.4 (kg/m3)							

Tab. 126 – Effect of planting date, variety selection and atmospheric CO₂ increase on the potential yield of tomato in Syros Island (Greece) under “present” and “future” climate conditions.

Irrigation strategy	Yield 2000 (*)	Yield 2050 (*)		Yield 2050 wp_adj (**)		Yield 2050 late_var (*)	
	(t/ha)	(t/ha)	(variation vs 2000)	(t/ha)	(variation vs 2000)	(t/ha)	(variation vs 2000)
Mar 1st	65.3	62.1	-4.8%	74.6	14.2%	67.4	3.3%
Mar 15 th	63.5	60.1	-5.4%	72.1	13.5%	65.5	3.1%
Apr 1st	61.3	58.0	-5.4%	69.6	13.5%	63.6	3.6%
Apr 15th	59.6	56.6	-4.9%	68.0	14.1%	62.0	4.1%
May 1st	58.1	55.3	-4.8%	66.3	14.2%	60.5	4.3%
average	61.6	58.4	-5.1%	70.1	13.9%	63.8	3.7%
(*) assuming wp (2000) = 12 (kg/m3)							
(**) assuming wp (2050)= wp(2000)*1.2= 14.4 (kg/m3)							

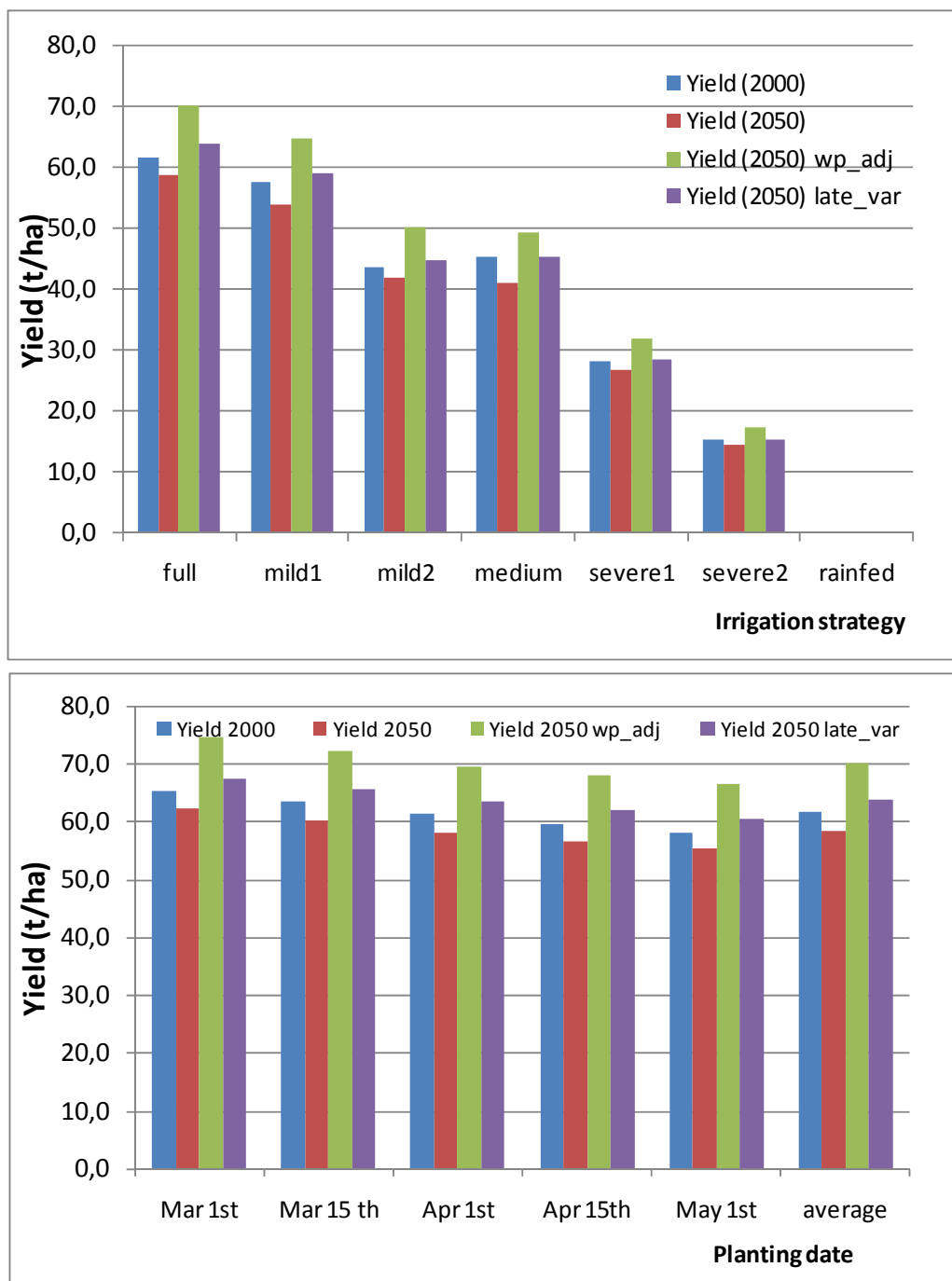


Fig. 103 – Effect of planting date, irrigation strategies, variety selection and atmospheric CO₂ increase on potential yield of tomato in Syros Island (Greece) under “present” and “future” climate conditions.

6.4. Potato

6.4.1. Cycle length and crop coefficient curves

The effect of temperature increase (and relative GDD accumulation) on current and projected crop cycle length and corresponding crop coefficient curves is represented in the following graphs, and the following observations have to be highlighted:

- if varietal adaptation is not considered, an important reduction of the total growing cycle is predicted for all planting dates, because of the faster accumulation of the required GGD sum under “future” climate conditions (2050) (fig. 104-105);
- if a late maturing variety will be used, the total crop cycle length (2050 late_var) is projected to remain relatively the same as for the current variety under “present” climate conditions (2000), especially for late planting dates (fig. 105);
- with respect to the four crop coefficient stages, a relative reduction is predicted in proportion to the corresponding increase in the cumulative GDD (lower during winter, higher during spring-summer months), but with a greater effect in the case of early (October) rather than late (February) planting dates (fig. 104).

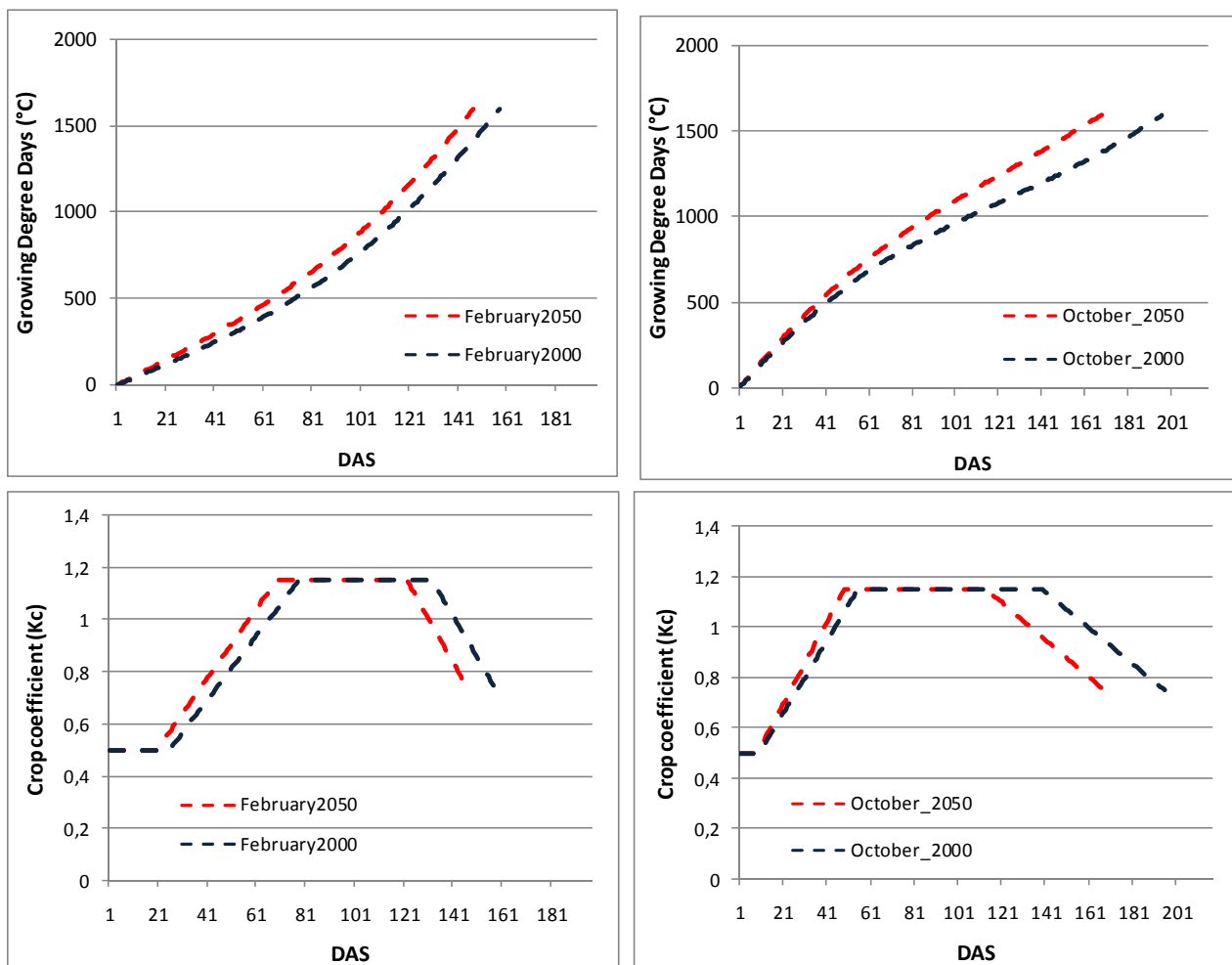


Fig. 104 – Predicted cumulative GDD and corresponding Kc curves for potato in Syros Island (Greece) as affected by different planting dates and climate scenarios.

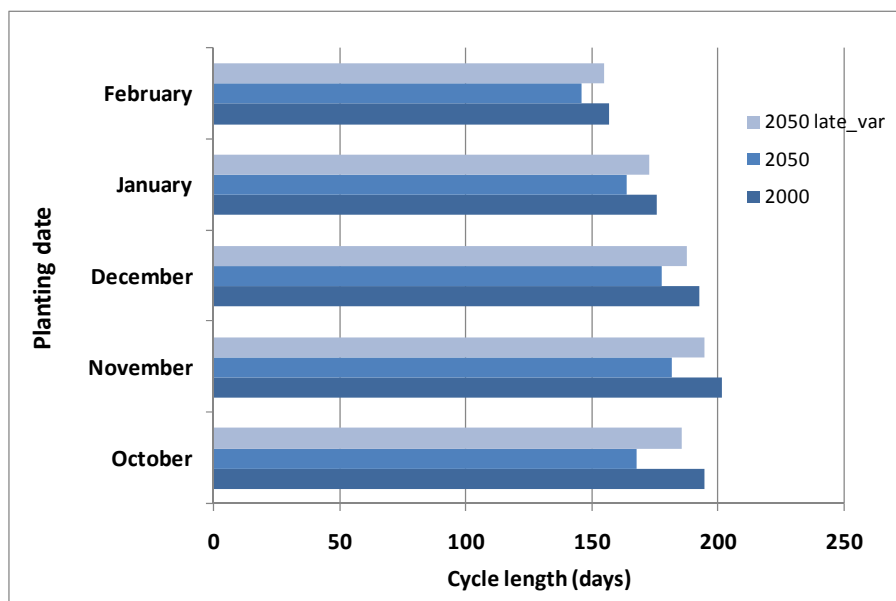


Fig. 105 – Length of total growing cycle of potato in Syros Island (Greece) as affected by planting date, variety selection and climate variations.

6.4.2. Crop evapotranspiration and irrigation requirements

The impact of climate change on maximum and effective crop evapotranspiration as well as on net irrigation requirements, also considering the relative effect of selected adaptation strategies (planting dates, variety selection and deficit irrigation strategies), is summarized in the following tables and graphs. In brief, the following observations are reported:

- maximum seasonal crop evapotranspiration is projected to reduce for the current variety under “future” (2050) scenario as a consequence of the expected shortening of the crop growing cycle, on average of about -7.5% with respect to current conditions (2000) (fig. 107 and tab.127);
- on the contrary, if a late maturing variety (2050 late_var) is selected, maximum evapotranspiration is projected to increase slightly (on average of about 1.9%) (fig. 107 and tab.127);
- the relative effect of the projected variation of rainfall patterns seems slightly important for the crop water balance, with an average reduction of about -23.7 mm during the cropping cycle (tab.128);
- maximum seasonal crop evapotranspiration is observed always to increase (in absolute terms) towards a peak for the planting dates of winter months with respect to earlier ones (fig. 107 and tab.127);
- effective seasonal crop evapotranspiration and net irrigation requirements are both highly dependent on the irrigation strategy, progressively reducing going from full irrigation to rainfed conditions (fig. 107 and tab.129-130);
- as for ET_{c_max} , also the ET_{c_eff} and NIR are projected to decrease in 2050 if the current variety is used; on the other side, if a late maturing variety is selected, while ET_{c_eff} is projected to remain relatively stable or to increase slightly, NIR is always projected to increase (fig. 107 and tab.129-130);

Tab. 127 – Effect of planting date and variety selection on the maximum crop evapotranspiration of potato in Syros Island (Greece) under “present” and “future” climate conditions.

Planting date	ETc_max 2000	ETc_max 2050		ETc_max 2050 late_var	
	[mm/season]	[mm/season]	(variation vs 2000)	[mm/season]	(variation vs 2000)
october	469.9	412.6	-12.2%	462.7	-1.5%
november	512.4	464.4	-9.4%	512.8	0.1%
december	518.3	485.0	-6.4%	528.5	2.0%
january	496.7	470.8	-5.2%	516.3	4.0%
february	506.3	483.6	-4.5%	530.8	4.8%
average	500.7	463.3	-7.5%	510.2	1.9%

Tab. 128 – Effect of planting date and variety selection on the effective rainfall pattern during crop cycle of potato in Syros Island (Greece) under “present” and “future” climate conditions.

Planting date	Rain_eff 2000	Rain_eff 2050		Rain_eff 2050 late_var	
	[mm/season]	[mm/season]	(variation vs 2000)	[mm/season]	(variation vs 2000)
october	209.8	169.5	-19.2%	173.9	-17.1%
november	176.5	158.5	-10.2%	161.3	-8.6%
december	150.5	137.1	-8.9%	138.7	-7.9%
january	83.8	65.2	-22.2%	65.2	-22.2%
february	78.1	50.2	-35.7%	50.2	-35.7%
average	139.8	116.1	-16.9%	117.8	-15.7%

Tab. 129 – Effect of irrigation strategies and variety selection on the effective evapotranspiration of potato in Syros Island (Greece) under “present” and “future” climate conditions.

Irrigation strategy	ETc_eff 2000	ETc_eff 2050		ETc_eff 2050 late_var	
	[mm/season]	[mm/season]	(variation vs 2000)	[mm/season]	(variation vs 2000)
full	500.6	463.3	-7.5%	510.1	1.9%
mild1	479.9	443.3	-7.6%	487.0	1.5%
mild2	449.5	416.4	-7.4%	453.9	1.0%
medium	426.1	393.2	-7.7%	428.4	0.5%
severe1	384.9	353.2	-8.2%	382.6	-0.6%
severe2	315.5	287.7	-8.8%	307.2	-2.6%
rainfed	203.9	182.0	-10.7%	185.8	-8.9%

Tab. 130 – Effect of irrigation strategies and variety selection on the net irrigation requirements of potato in Syros Island (Greece) under “present” and “future” climate conditions.

Irrigation strategy	NIR 2000	NIR 2050		NIR 2050 late_var	
	[mm/season]	[mm/season]	(variation vs 2000)	[mm/season]	(variation vs 2000)
full	354.7	345.1	-2.7%	388.6	9.6%
mild1	326.1	308.2	-5.5%	353.1	8.3%
mild2	283.7	276.1	-2.7%	310.9	9.6%
medium	263.4	248.5	-5.6%	278.1	5.6%
severe1	211.9	200.3	-5.5%	229.5	8.3%
severe2	131.7	124.3	-5.6%	139.0	5.6%
rainfed	0.0	0.0	0.0%	0.0	0.0%

- by plotting together the values of seasonal ETc_{eff} and NIR (obtained under different irrigation strategies and variety) for different climate scenarios, there is a clear prediction of their reduction (respectively of about -7.9% and -4.2%, on average) and, by considering a late maturing variety, a relative stability of ETc_{eff} (+0.3%) and an increase of NIR is predicted (+8.2%) (fig. 106);
- the cumulative curves of ETc_{max} in 2050 (versus 2000) show always a clear shifting towards higher values, thus representing the relative increase in the daily crop water requirements, although with a decrease in the cumulative final value (depending on the anticipated ending of the cycle) (fig. 108).

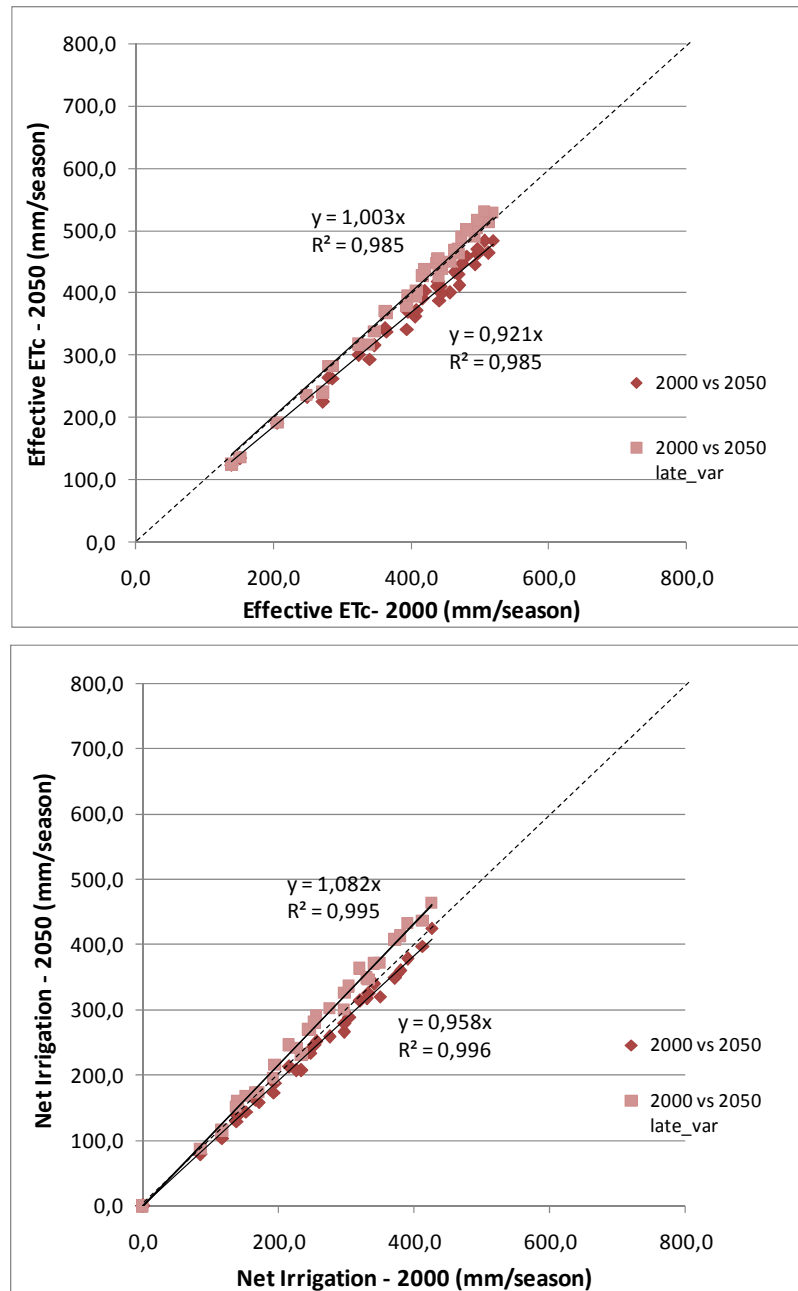


Fig. 106 – Scatter-plot of seasonal crop evapotranspiration and net irrigation requirements of as affected by different variety selection for potato in Syros Island (Greece) under “present” and “future” climate conditions.

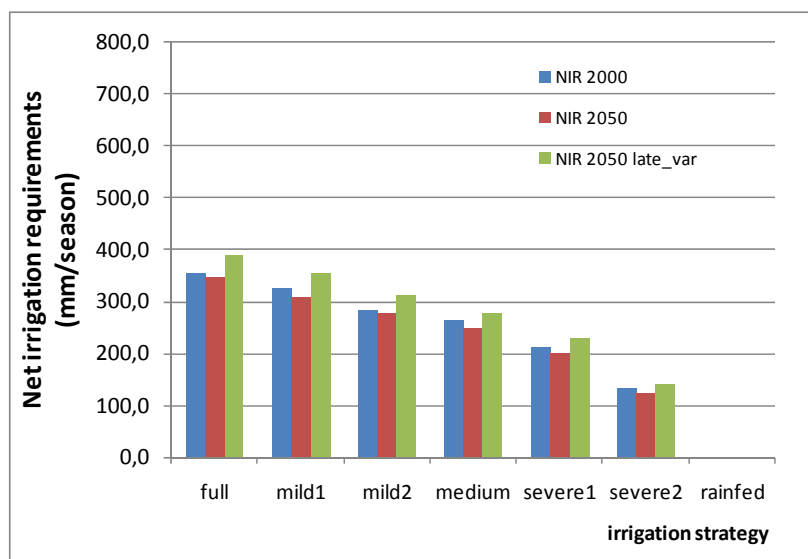
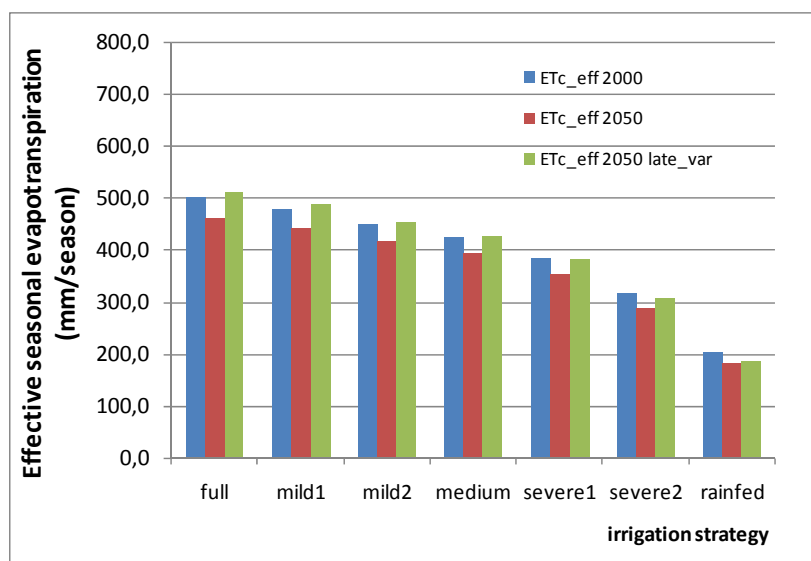
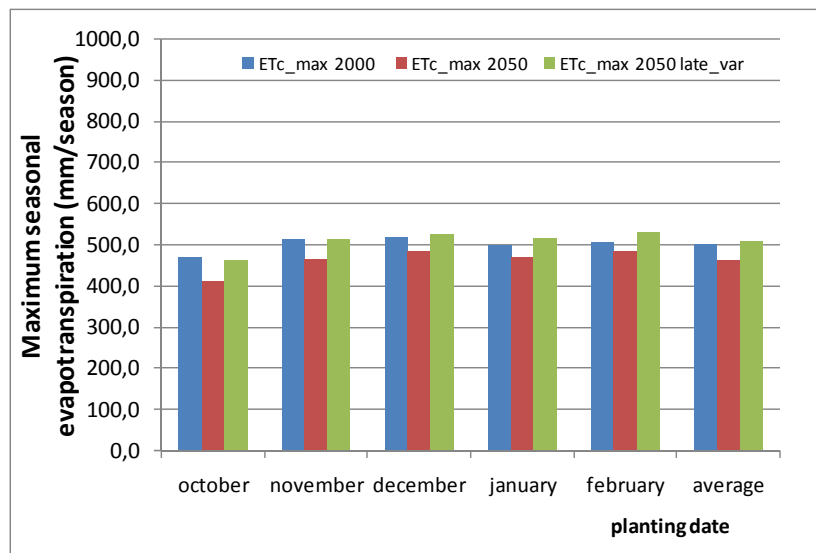


Fig. 107 – Effect of planting date, irrigation strategies and variety selection on maximum and effective crop evapotranspiration and net irrigation requirements of potato in Syros Island (Greece) under “present” and “future” climate conditions.

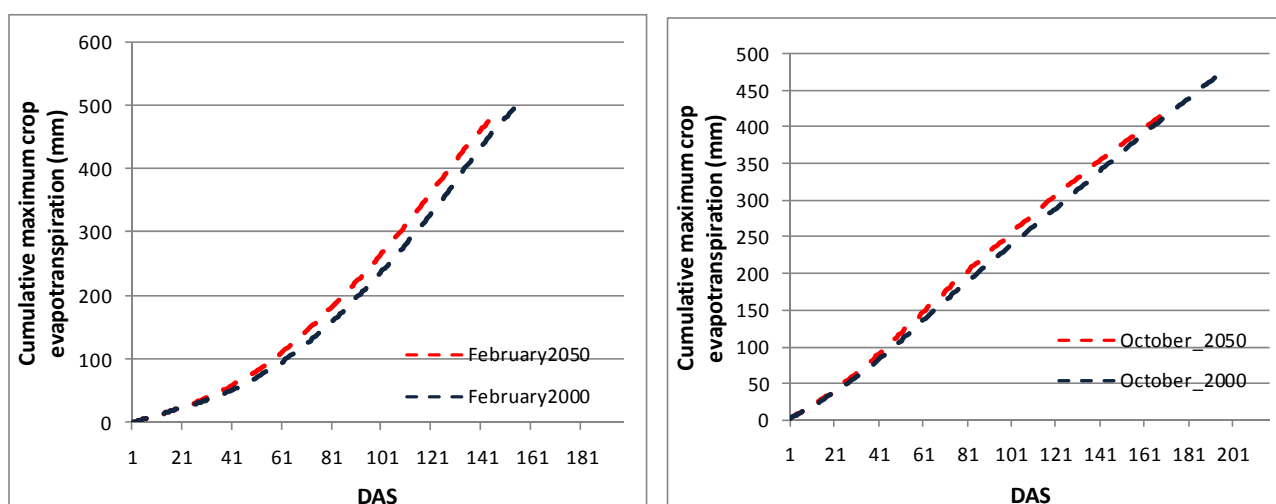


Fig. 108 – Cumulative curves of maximum crop evapotranspiration as affected by different planting date for potato in Syros Island (Greece) under “present” and “future” climate conditions.

6.4.3. Yield response to water

The impact of climate change on potential yield, also considering the relative effect of selected adaptation strategies (planting dates, variety selection and deficit irrigation strategies), is summarized in the following tables and graphs. In brief, the following observations are reported:

- yield is projected to reduce under “future” scenario (2050) with respect to current conditions (2000), on average from 32.5 to 30.1 t ha⁻¹ (about -7.5%), depending on irrigation strategies (tab. 131 and fig.109) and planting dates (tab. 132 and fig.109), as a consequence of the expected shortening of the crop growing cycle;
- on the contrary, if the expected fertilizing effect due to an increase in atmospheric CO₂ concentration will occur, yield (2050 wp_adj) is projected to increase in quite all conditions (with an average of 36.1 t ha⁻¹, +11%), and thus to overcome the effect of the shortening of the crop cycle (fig. 109 and tab.131-132);
- on the other side, if a late maturing variety (2050 late_var) is selected, yield is projected to slightly increase (with an average of 33.2 t ha⁻¹, +1.9%), depending on irrigation strategy and planting dates (fig. 109 and tab.131-132);
- there is a clear reduction in potential yield under increasing water stress conditions (fig.109), and under “severe” water stress (thus only supported by supplemental irrigations) values of 18-25 t ha⁻¹ are predicted;
- in the case of rainfed conditions, low yield (around 12 t ha⁻¹) is expected in all conditions;
- yield is observed always to increase (in absolute terms) for winter planting dates with respect to earlier ones (fig.109), because of the corresponding increase in total maximum crop evapotranspiration.

Tab. 131 – Effect of irrigation strategies, variety selection and atmospheric CO₂ increase on the potential yield of potato in Syros Island (Greece) under “present” and “future” climate conditions.

Irrigation strategy	Yield 2000 (*) (t/ha)	Yield 2050 (*)		Yield 2050 wp_adj (**)		Yield 2050 late_var (*)	
		(t/ha)	(variation vs 2000)	(t/ha)	(variation vs 2000)	(t/ha)	(variation vs 2000)
full	32.5	30.1	-7.5%	36.1	11.0%	33.2	1.9%
mild1	30.8	28.6	-7.3%	34.3	11.2%	31.3	1.6%
mild2	28.6	26.6	-7.1%	31.9	11.5%	28.9	0.9%
medium	26.4	24.4	-7.6%	29.3	10.9%	26.5	0.5%
severe1	23.5	21.7	-8.0%	26.0	10.4%	23.3	-1.1%
severe2	18.6	17.0	-8.6%	20.4	9.7%	18.0	-3.3%
rainfed	12.1	11.0	-9.4%	13.2	8.7%	11.2	-8.1%
(*) assuming wp (2000) = 6.5 (kg/m3)							
(**) assuming wp (2050)= wp(2000)*1.2= 7.8 (kg/m3)							

Tab. 132 – Effect of planting date, variety selection and atmospheric CO₂ increase on the potential yield of potato in Syros Island (Greece) under “present” and “future” climate conditions.

Irrigation strategy	Yield 2000 (*) (t/ha)	Yield 2050 (*)		Yield 2050 wp_adj (**)		Yield 2050 late_var (*)	
		(t/ha)	(variation vs 2000)	(t/ha)	(variation vs 2000)	(t/ha)	(variation vs 2000)
october	30.5	26.8	-12.2%	32.2	5.4%	30.1	-1.5%
november	33.3	30.2	-9.4%	36.2	8.7%	33.3	0.1%
december	33.7	31.5	-6.4%	37.8	12.3%	34.3	2.0%
january	32.3	30.6	-5.2%	36.7	13.7%	33.6	4.0%
february	32.9	31.4	-4.5%	37.7	14.6%	34.5	4.8%
average	32.5	30.1	-7.5%	36.1	11.0%	33.2	1.9%
(*) assuming wp (2000) = 6.5 (kg/m3)							
(**) assuming wp (2050)= wp(2000)*1.2= 7.8 (kg/m3)							

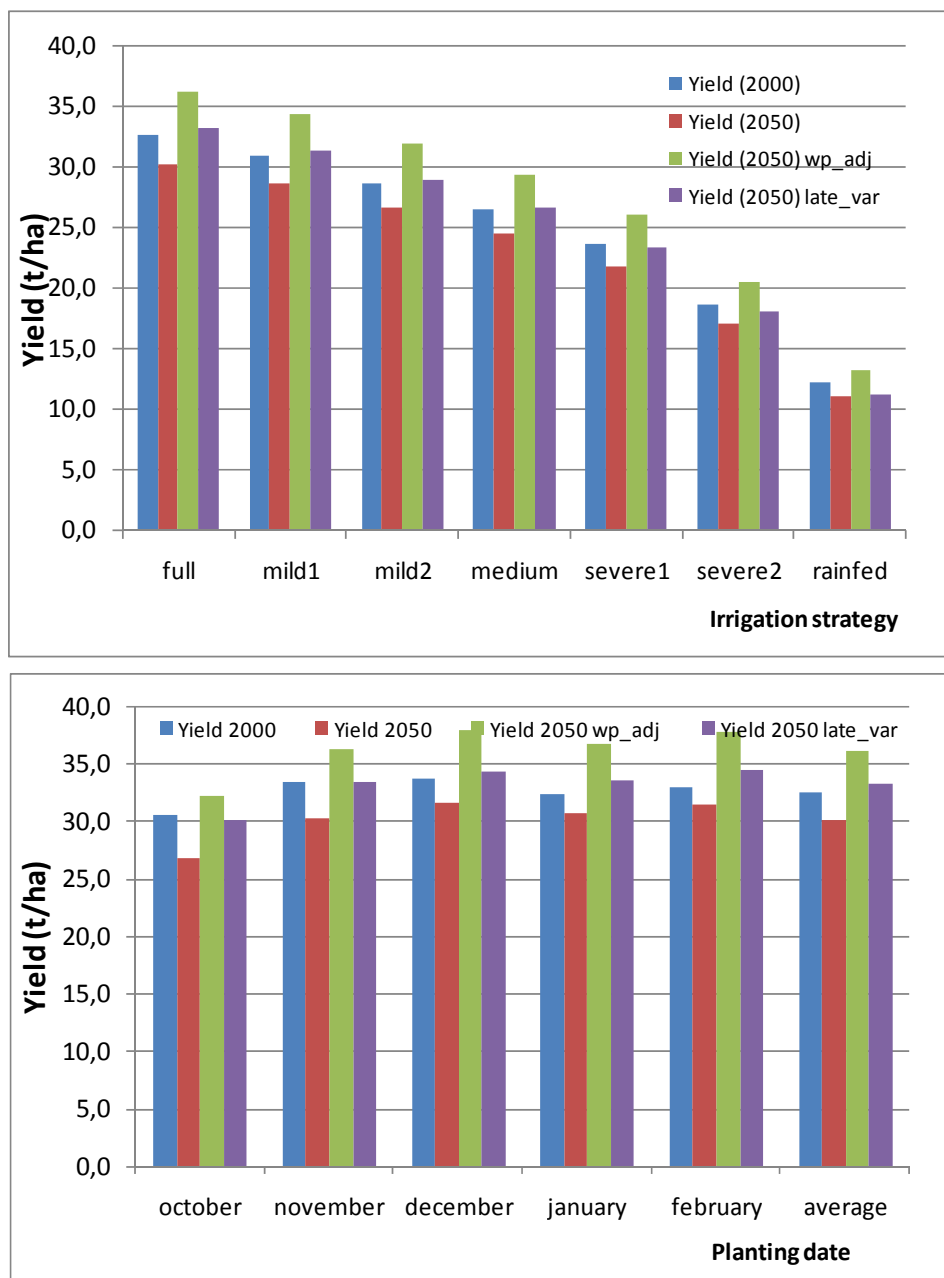


Fig. 109 – Effect of planting date, irrigation strategies, variety selection and atmospheric CO₂ increase on potential yield of potato in Syros Island (Greece) under “present” and “future” climate conditions.

6.5. Olive

6.5.1. Cycle length and crop coefficient curves

The effect of temperature increase (and relative GDD accumulation) on current and projected crop cycle of olive has not been evaluated, because of the lack of sufficient information and data to model the relative length of the stages. Thus, a fixed length of the stages and of total growing period has been considered (270 days), as suggested by FAO (2012).

The crop coefficient curves have been modelled by computing the average monthly K_c values according to Orgaz et al. (2006) and FAO (2012) under the different conditions of selected climate scenarios, as affected by the changing of monthly ET_o and rainfall pattern and especially of their relative effect on the evaporative K_c components (from soil and canopy). In table 133, a comparison of the main K_c components is reported, showing the relative reduction of the canopy direct evaporative component (K_{pd}) and of the soil evaporation component ($K_{s,e}$) during the autumn to winter months, due to the projected relative decrease in rainfall pattern and increase in reference evapotranspiration.

In the figure 110, the monthly trends of crop coefficients under different climate scenarios are reported, as computed according to Orgaz et. (2006) for a “new” and an “old” type of olive crop plantation, and in comparison to the fixed K_c coefficient suggested by FAO (2012) for an arid environment; the following observations are reported:

- there is a clear effect of the type of plantation on K_c values, being higher for “new” types of cropping systems under all climate scenarios;
- as yet mentioned, the K_c values for autumn-winter months progressively reduce because of the reduction in projected ET_o and rainfall patterns;
- only slight variations are observed during the spring-summer months, where the K_{pd} and $K_{s,e}$ components reduce close to zero and no variations are observed between scenarios.

Tab. 133 - Comparison of monthly K_c values and main components for olive in Syros Island (Greece) under “present”, “future” and “extreme weather” climate conditions.

Month	Kc			Kc.tr	Kpd			Ks.e		
	2000	2050	2050+1	Avg	2000	2050	2050+1	2000	2050	2050+1
1	0.84	0.93	0.81	0.26	0.12	0.16	0.11	0.41	0.46	0.39
2	0.97	0.75	0.66	0.27	0.17	0.08	0.06	0.47	0.33	0.27
3	0.77	0.68	0.61	0.29	0.08	0.06	0.04	0.33	0.27	0.22
4	0.59	0.57	0.54	0.33	0.02	0.02	0.01	0.17	0.16	0.14
5	0.58	0.55	0.53	0.38	0.01	0.01	0.00	0.12	0.10	0.09
6	0.57	0.58	0.57	0.46	0.00	0.00	0.00	0.06	0.06	0.05
7	0.58	0.56	0.55	0.46	0.00	0.00	0.00	0.06	0.04	0.03
8	0.58	0.55	0.54	0.44	0.01	0.00	0.00	0.07	0.05	0.04
9	0.62	0.64	0.60	0.40	0.02	0.03	0.02	0.13	0.15	0.12
10	0.96	0.76	0.71	0.44	0.12	0.04	0.03	0.34	0.22	0.18
11	0.90	0.93	0.84	0.40	0.09	0.10	0.07	0.35	0.36	0.30
12	0.95	0.95	0.84	0.26	0.17	0.18	0.12	0.47	0.46	0.40

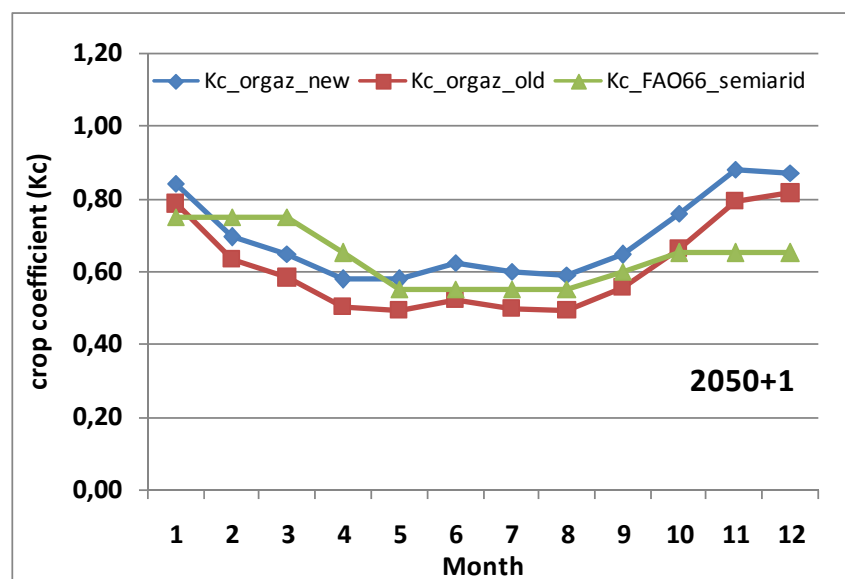
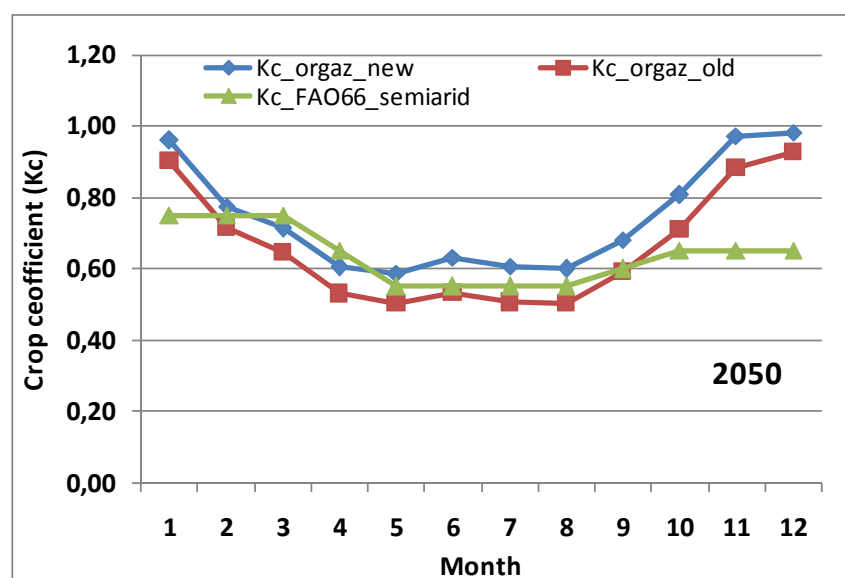
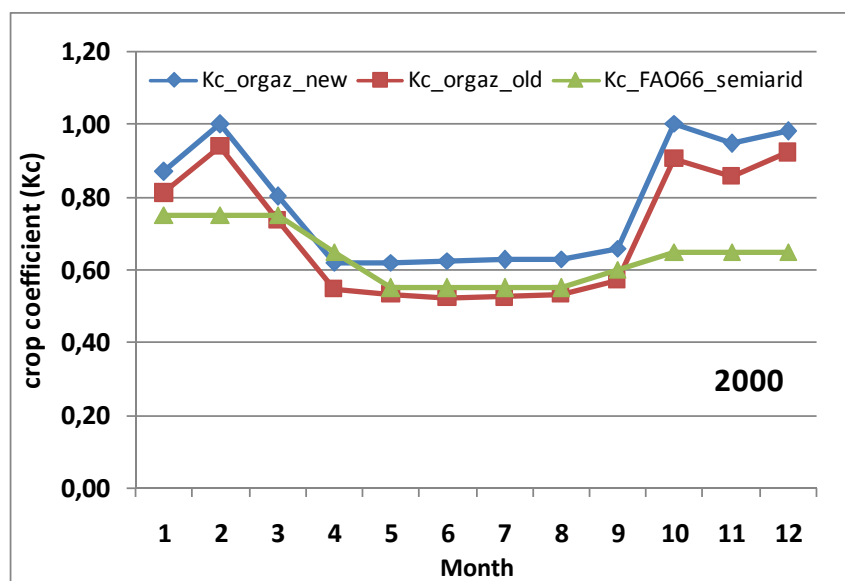


Fig. 110 - Trends of monthly Kc coefficients for olive in Syros Island (Greece) under “present”, “future” and “extreme weather” climate conditions.

6.5.2. Crop evapotranspiration and irrigation requirements

The impact of climate change on maximum and effective crop evapotranspiration as well as on net irrigation requirements, also considering the relative effect of selected adaptation strategies (deficit irrigation strategies), is summarized in the following tables and graphs. In brief, the following observations are reported:

- maximum seasonal crop evapotranspiration is projected to increase for all crop models under “future” (2050) scenario, because of the fixed duration of cycle length and probably as a consequence of the expected increase in daily ET_o , on average of about +1.7% with respect to current conditions (2000) (fig. 111 and tab.134);
- if “extreme weather” conditions (2050+1) are considered, the projected maximum evapotranspiration variation is slightly higher (on average of about +2.3%), but with some differences between the models (fig. 111 and tab.134);
- the higher values of maximum seasonal crop evapotranspiration are observed for the “new” cropping type, under all climate scenarios (fig. 111 and tab.134);
- the relative effect of the projected increase and/or decrease of rainfall patterns (during the period March-November), seems to be relatively important for the crop water balance, especially under “extreme weather” scenario (about -60 mm), and with respect to the impact for the rainfed strategy (in which rain is the only source of water) (tab.135);
- ETc_{eff} and NIR are both highly dependent on the irrigation strategy, progressively reducing going from full irrigation to rainfed conditions, under all climate scenarios (fig.111 and tab.136-137);
- ETc_{eff} is projected to increase under both 2050 (on average +1.3%) and 2050+1 (+1.4%) scenarios, for all irrigation strategies with the exception of severe stressed and rainfed conditions (on average -4.2% and -8.7%), in which a reduction is projected because of the reduction of the rainfall patterns, especially under “extreme weather” scenario;
- as a consequence, NIR is projected to increase for all irrigation strategies under both 2050 (on average +6.6%) and 2050+1 (+17.7%) scenarios.

Tab. 134 – Maximum crop evapotranspiration as estimated by different Kc models for olive in Syros Island (Greece) under “present”, “future” and “extreme weather” climate conditions.

Crop model	ETc_max 2000	ETc_max 2050		ETc_max 2050 +1	
	[mm/season]	[mm/season]	(variation vs 2000)	[mm/season]	(variation vs 2000)
Old_Orgaz_270	641.4	639.3	-0.3%	630.3	-1.7%
New_Orgaz_270	737.5	740.5	0.4%	735.4	-0.3%
FAO66_270	628.6	662.8	5.4%	688.3	9.5%
average	669.2	680.9	1.7%	684.7	2.3%

Tab. 135 – Effective rainfall pattern during crop cycle of olive in Syros Island (Greece) under “present”, “future” and “extreme weather” climate conditions.

Crop model	Rain_eff 2000	Rain_eff 2050		Rain_eff 2050 +1	
	[mm/season]	[mm/season]	(variation vs 2000)	[mm/season]	(variation vs 2000)
Old_Orgaz_270	119.0	88.9	-25.2%	62.3	-47.7%
New_Orgaz_270	119.0	88.9	-25.2%	62.3	-47.7%
FAO66_270	119.0	88.9	-25.2%	62.3	-47.7%
average	119.0	88.9	-25.2%	62.3	-47.7%

Tab. 136 – Effect of irrigation strategies on the effective crop evapotranspiration of olive in Syros Island (Greece) under “present”, “future” and “extreme weather” climate conditions.

Irrigation strategy	ETc_eff 2000	ETc_eff 2050		ETc_eff 2050+1	
	[mm/season]	[mm/season]	(variation vs 2000)	[mm/season]	(variation vs 2000)
full	669.2	680.9	1.7%	684.7	2.3%
mild1	648.8	656.7	1.2%	663.0	2.2%
mild2	598.4	605.2	1.1%	603.5	0.8%
medium	539.6	545.1	1.0%	539.9	0.1%
severe1	507.0	503.3	-0.7%	502.0	-1.0%
severe2	380.0	372.3	-2.0%	361.1	-5.0%
rainfed	219.9	198.3	-9.8%	175.4	-20.3%

Tab. 137 – Effect of irrigation strategies on the net irrigation requirements of olive in Syros Island (Greece) under “present”, “future” and “extreme weather” climate conditions.

Irrigation strategy	NIR 2000	NIR 2050		NIR 2050 +1	
	[mm/season]	[mm/season]	(variation vs 2000)	[mm/season]	(variation vs 2000)
full	507.5	542.8	6.9%	577.7	13.8%
mild1	472.5	487.6	3.2%	528.7	11.9%
mild2	406.0	434.2	6.9%	462.1	13.8%
medium	321.9	352.6	9.6%	409.6	27.2%
severe1	307.1	316.9	3.2%	343.6	11.9%
severe2	160.9	176.3	9.6%	204.8	27.2%
rainfed	0.0	0.0	0.0%	0.0	0.0%

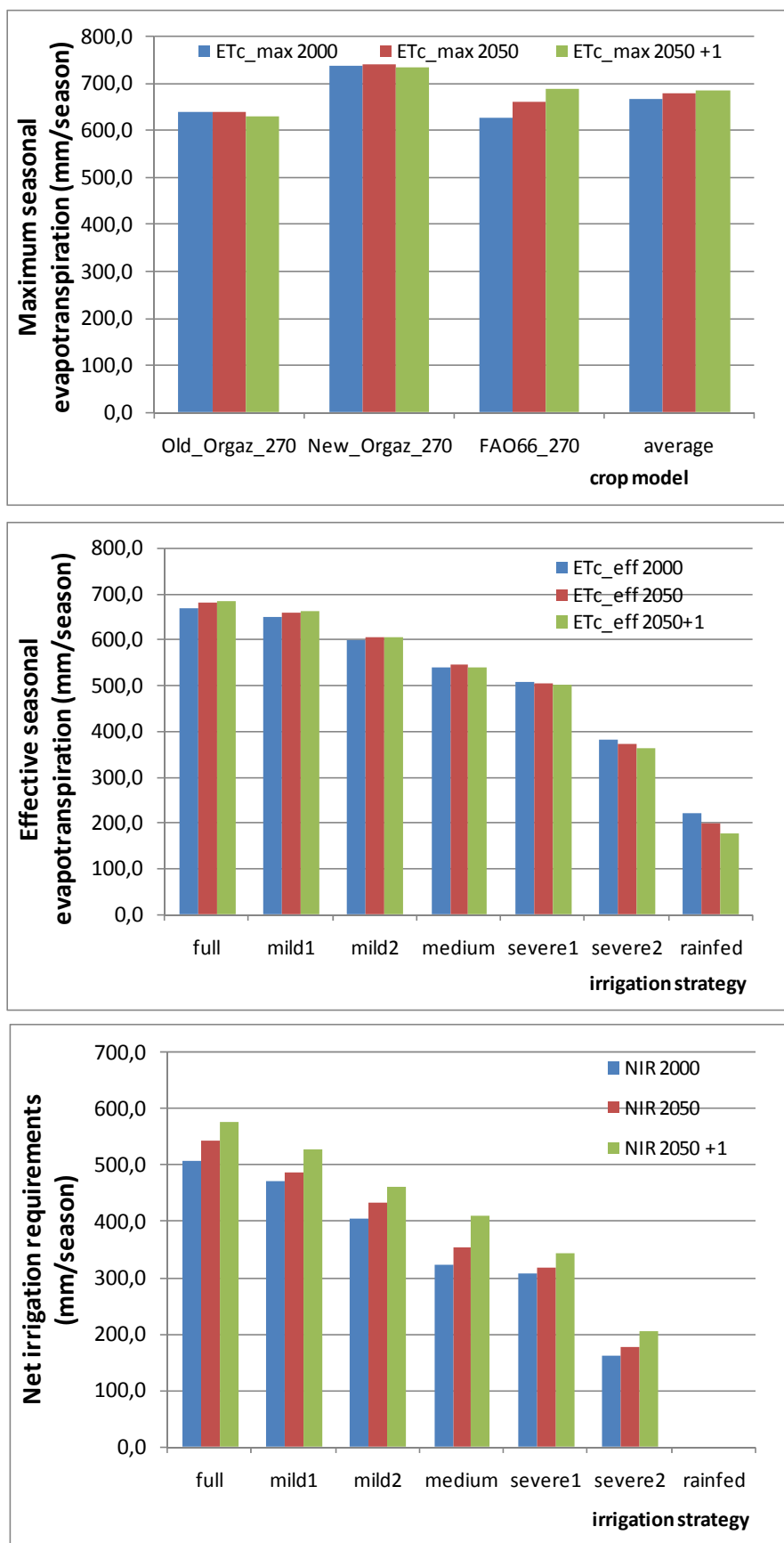


Fig. 111 – Effect of Kc model and irrigation strategies on maximum and effective crop evapotranspiration and net irrigation requirements of olive in Syros Island (Greece) under “present”, “future” and “extreme weather” climate conditions.

6.5.3. Yield response to water

The impact of climate change on potential yield, considering the relative effect of selected adaptation strategies (deficit irrigation strategies), as estimated by the two different yield response models of Rao *et al.* (1988) and Moriana *et al.* (2003) (presented in chapter 2.1.3) are summarized in the following tables and graphs.

According to the results of the first model (Rao *et al.*, 1988) (tab. 138-139 and fig.112):

- on average, yield is projected to increase under future scenarios, going from 10 t ha⁻¹ (2000) respectively to 10.2 t ha⁻¹ (2050) and 10.3 t ha⁻¹ (2050+1);
- yield is projected to increase and/or decrease under “future” (2050) and “extreme weather” (2050+1) scenarios with respect to current conditions (2000), depending on irrigation strategies and Kc model considered, as a consequence of the expected increase of ETC;
- an important reduction in yield is predicted for severe stressed and rainfed conditions, on average from -5.7% for 2050 to -9.8 for 2050+1;
- under “severe” water stress (thus only supported by supplemental irrigations) values of 3.5-6 t ha⁻¹ are still predicted; in the case of rainfed conditions, very low yield (around 1 t ha⁻¹) is predicted.

According to the results of the alternative model (Moriana *et al.*, 2003) (tab. 140-141 and fig.113):

- on average, yield is projected to increase under future scenarios, going from 9.6 t ha⁻¹ (2000) respectively to 9.8 t ha⁻¹ (2050) and 9.9 t ha⁻¹ (2050+1);
- yield is projected to slightly increase from full irrigated to medium stressed conditions under both “future” and “extreme weather” scenarios, respectively on average +1.8% and 1.6%; on the contrary, under severe stressed conditions, yield reductions respectively from -7.8% to -18.3% are predicted;
- a linear decrease in potential yield is predicted going from full irrigated to severe stress (only supported by supplemental irrigations) where values of 2-6 t ha⁻¹ are still predicted; in the case of rainfed conditions, no yield is predicted.

Tab. 138 – Effect of irrigation strategies on the potential yield of olive in Syros Island (Greece) under “present”, “future” and “extreme weather” climate conditions.

Irrigation strategy	Yield 2000 (*)	Yield 2050 (*)		Yield 2050 +1 (*)	
	(t/ha)	(t/ha)	(variation vs 2000)	(t/ha)	(variation vs 2000)
full	10.0	10.2	1.7%	10.3	2.3%
mild1	9.6	9.6	1.0%	9.8	2.2%
mild2	7.9	7.9	0.1%	7.9	-1.0%
medium	7.1	7.1	0.3%	7.0	-1.4%
severe1	5.8	5.7	-1.8%	5.6	-3.0%
severe2	3.6	3.5	-4.2%	3.3	-7.7%
rainfed	1.0	0.9	-11.1%	0.9	-18.7%
(*) assuming wp (2000) =		1.5	(kg/m3)		

Tab. 139 – Effect of different Kc models on the potential yield of olive in Syros Island (Greece) under “present” and “future” climate conditions.

Crop model	Yield 2000 (*)	Yield 2050 (*)		Yield 2050 +1 (*)	
	(t/ha)	(t/ha)	(variation vs 2000)	(t/ha)	(variation vs 2000)
Old_Orgaz_270	9.6	9.6	-0.3%	9.5	-1.7%
New_Orgaz_270	11.1	11.1	0.4%	11.0	-0.3%
FAO66_270	9.4	9.9	5.4%	10.3	9.5%
average	10.0	10.2	1.7%	10.3	2.3%
(*) assuming wp (2000) =		1.5	(kg/m3)		

Tab. 140 – Effect of irrigation strategies on the potential yield of olive in Syros Island (Greece) (as modelled according to Moriana *et al.* 2003) under “present”, “future” and “extreme weather” climate conditions.

Irrigation strategy	Yield 2000 (**)	Yield 2050 (**)		Yield 2050 +1 (**)	
	(t/ha)	(t/ha)	(variation vs 2000)	(t/ha)	(variation vs 2000)
full	9.6	9.8	1.9%	9.9	2.5%
mild1	9.3	9.4	1.5%	9.5	2.6%
mild2	8.3	8.5	1.7%	8.4	1.3%
medium	7.0	7.1	2.0%	7.0	0.1%
severe1	6.1	6.0	-1.7%	6.0	-2.3%
severe2	2.0	1.8	-13.9%	1.3	-34.3%
rainfed	0.0	0.0		0.0	
(**) according to the model proposed by Moriana <i>et al.</i> (2003)					

Tab. 141 – Effect of different Kc models on the potential yield of olive in Syros Island (Greece) (as modelled according to Moriana *et al.* 2003) under “present” and “future” climate conditions.

Crop model	Yield 2000 (**)	Yield 2050 (**)		Yield 2050 (**)	
	(t/ha)	(t/ha)	(variation vs 2000)	(t/ha)	(variation vs 2000)
Old_Orgaz_270	9.2	9.1	-0.4%	9.0	-2.2%
New_Orgaz_270	10.6	10.6	0.3%	10.6	-0.2%
FAO66_270	8.9	9.5	6.8%	9.9	11.3%
average	9.6	9.8	1.9%	9.9	2.5%
(**) according to the model proposed by Moriana <i>et al.</i> (2003)					

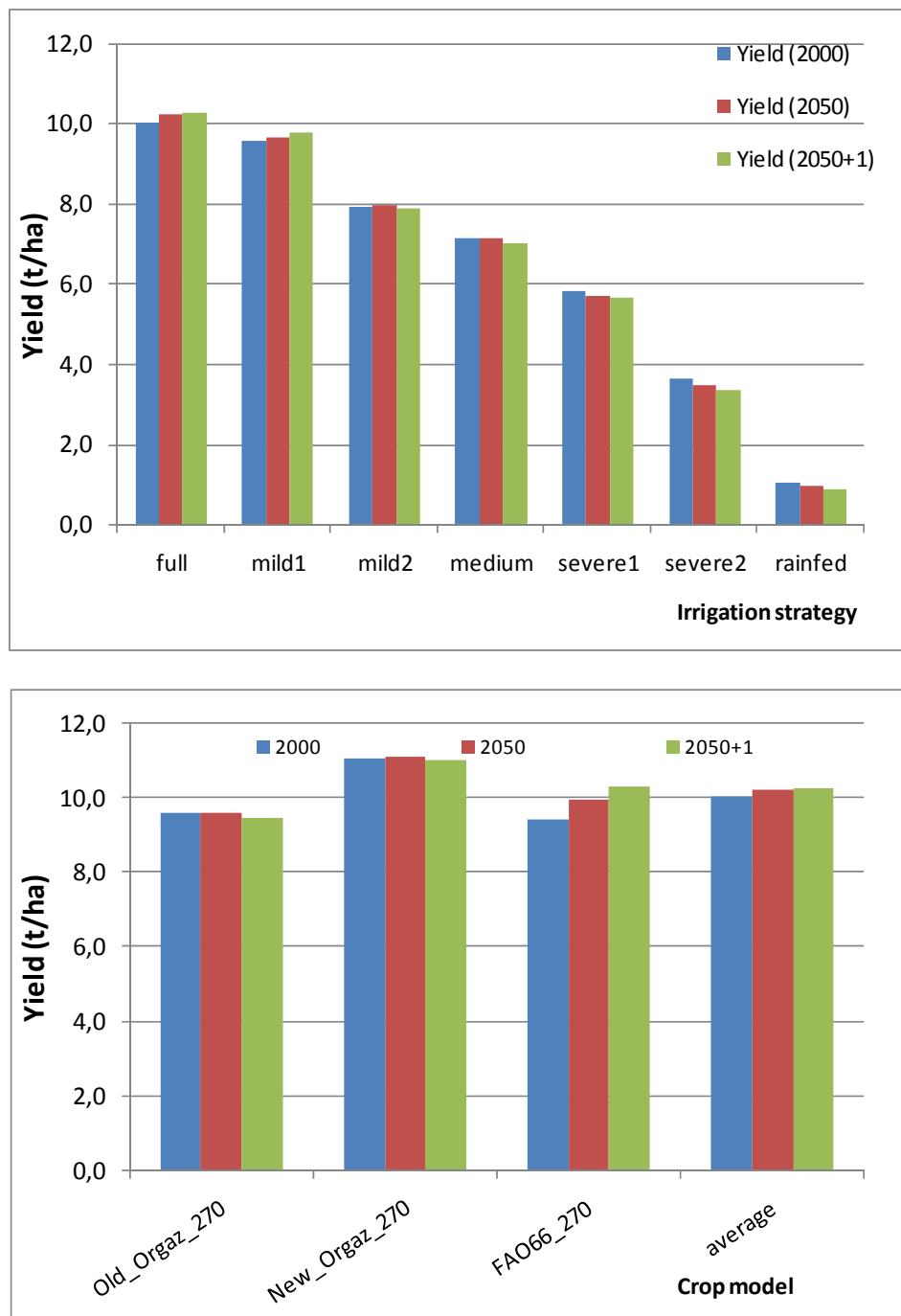


Fig. 112 – Effect of irrigation strategies and Kc model on potential yield of olive in Syros Island (Greece) under “present” and “future” climate conditions.

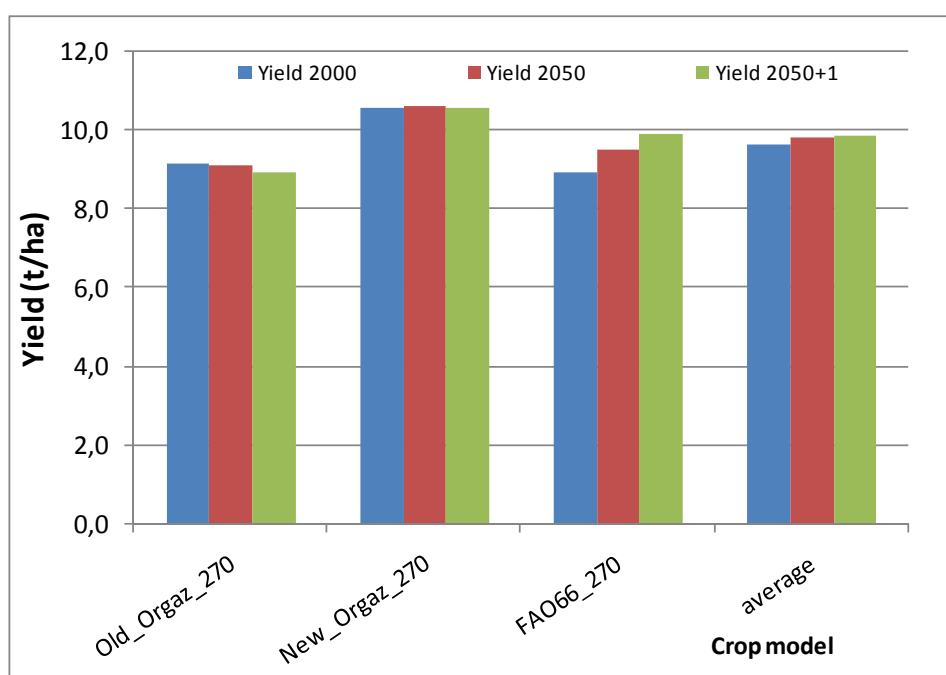
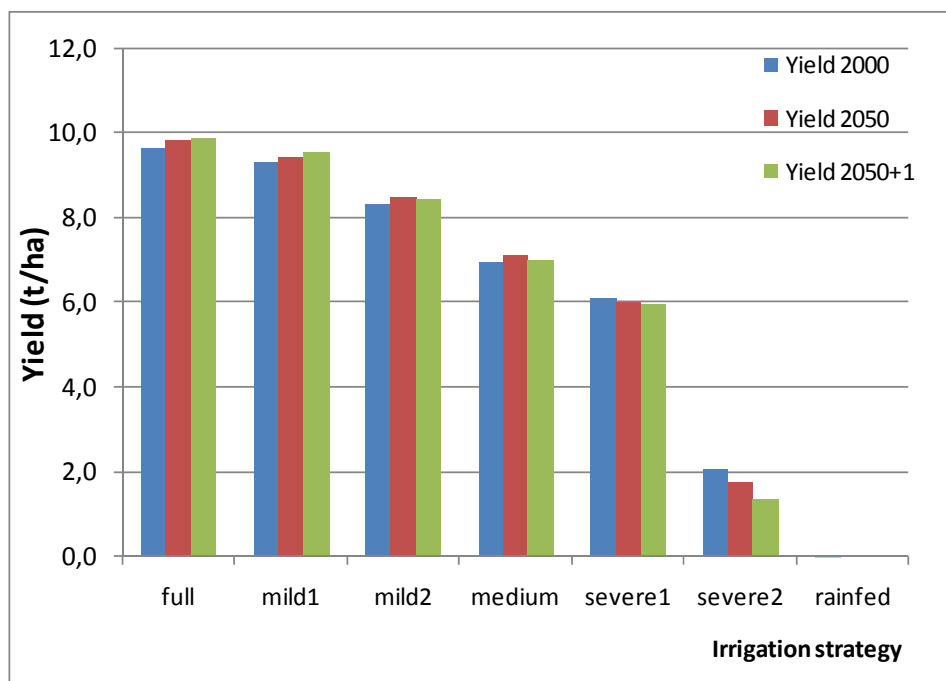


Fig. 113 – Effect of irrigation strategies and Kc model on potential yield of olive in Syros Island (Greece) (as modelled according to Moriana *et al.* 2003) under “present” and “future” climate conditions.

7. Case study: Sardinia Region (Italy)

7.1. Climate projections and reference evapotranspiration

With respect to climate projections, as summarized in the following tables and graphs, the following observation are predicted:

- an important reduction of the annual rainfall pattern (-44.6 mm/year), with wide variations (increasing or decreasing) at monthly scale, with the higher reductions predicted in May, but with some relevant increase in February and August;
- an important increase (+74.1 mm/year) of annual reference evapotranspiration, especially during spring-summer months (with values up to +11.7 mm/month in July), and with a “peak” of daily evapotranspiration in July (6.1 mm/day);

Tab. 142 – Monthly and annual average values of predicted rainfall and evapotranspiration under present and future climate conditions

Month	Rain			ETo		
	2000	2050	var. (mm)	2000	2050	var. (mm)
1	102.6	99.6	-2.9	46.1	47.8	1.6
2	34.2	57.2	22.9	50.8	52.6	1.8
3	76.6	65.2	-11.4	71.4	75.7	4.2
4	41.2	45.1	3.9	90.6	96.6	6.0
5	38.2	6.8	-31.4	124.9	134.7	9.8
6	12.3	9.7	-2.6	155.9	167.5	11.6
7	12.0	12.3	0.3	178.6	190.3	11.7
8	7.2	28.0	20.8	163.9	173.8	10.0
9	52.9	47.4	-5.5	120.5	128.3	7.9
10	91.1	85.0	-6.0	82.6	87.5	4.9
11	76.6	68.2	-8.4	55.6	57.4	1.8
12	109.1	84.9	-24.2	45.7	48.6	2.9
Total	654.1	609.5	-44.6	1186.7	1260.8	74.1

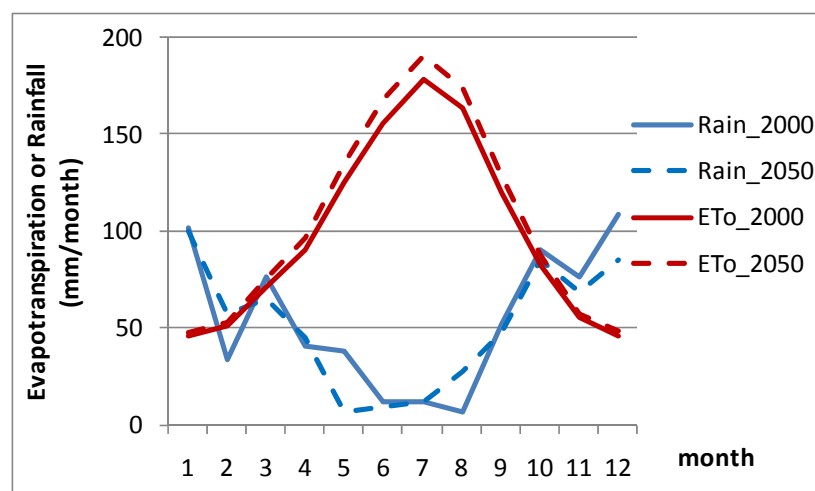


Fig. 114 – Monthly trends of predicted rainfall and evapotranspiration under present and future climate conditions

- an important increase in annual average maximum, minimum and average air temperatures, up to +1.3°C;
- a relatively uniform increase in monthly average maximum, minimum and average air temperature, with the higher increases of +1.8 to 2°C during summer months;
- an increase in the “peak” air temperature during the hotter months of July-August, with average maximum value projected to reach around 29°C.

Tab. 143 – Monthly and annual average values and relative variations of predicted maximum, minimum and average air temperature under present and future climate conditions.

	Tmax			Tmin			Tmean		
Month	2000	2050	var. (°C)	2000	2050	var. (°C)	2000	2050	var. (°C)
1	12.0	12.9	1.0	7.6	8.5	0.9	9.8	10.7	0.9
2	12.4	13.5	1.2	7.4	8.6	1.2	9.9	11.0	1.2
3	14.0	14.7	0.8	8.3	9.1	0.8	11.1	11.9	0.8
4	16.3	17.3	1.0	10.0	10.9	0.9	13.1	14.1	1.0
5	19.8	21.2	1.5	12.5	13.7	1.2	16.1	17.5	1.3
6	24.3	25.7	1.5	15.8	17.1	1.3	20.0	21.4	1.4
7	27.2	28.9	1.7	18.3	20.0	1.6	22.8	24.5	1.7
8	27.3	29.1	1.8	18.6	20.4	1.8	23.0	24.7	1.8
9	24.3	26.3	2.0	16.7	18.7	2.0	20.5	22.5	2.0
10	20.1	21.5	1.5	14.1	15.5	1.4	17.1	18.5	1.4
11	16.0	17.0	1.0	11.1	12.2	1.1	13.5	14.6	1.1
12	12.9	14.2	1.3	8.5	9.8	1.2	10.7	12.0	1.3
Average	18.9	20.2	1.3	12.4	13.7	1.3	15.6	17.0	1.3

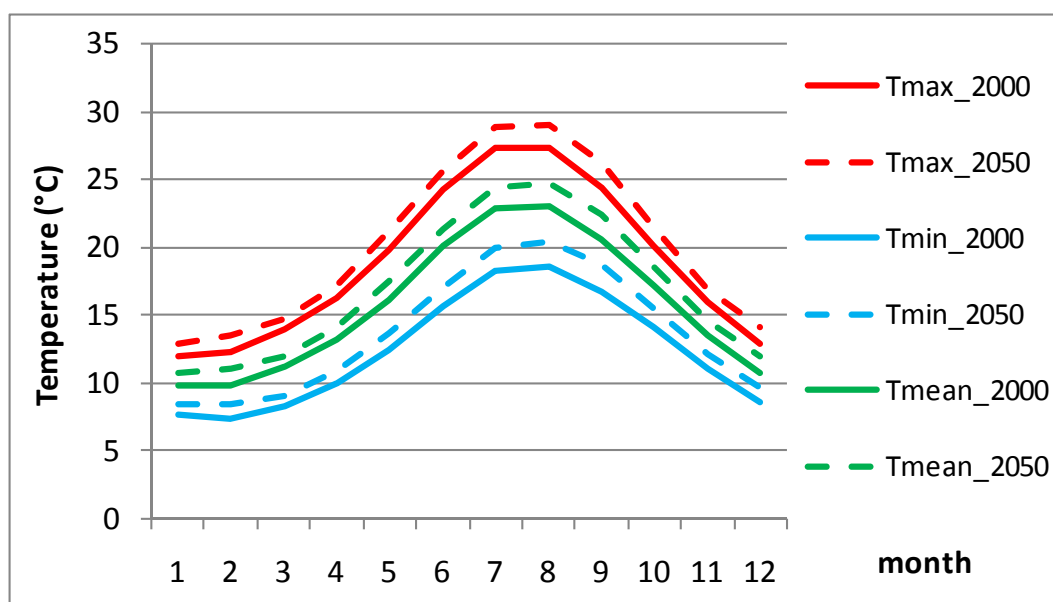


Fig. 115 – Monthly trends of predicted maximum, minimum and mean air temperatures under present and future climate conditions

7.2. Wheat

7.2.1. Cycle length and crop coefficient curves

The effect of temperature increase (and relative GDD accumulation) on current and projected crop cycle length and corresponding crop coefficient curves is represented in the following graphs, and the following observations have to be highlighted:

- if varietal adaptation is not considered, an important reduction of the total growing cycle is predicted for all planting dates, because of the faster accumulation of the required GGD sum under “future” climate conditions (2050) (fig. 116-117);
- on the contrary, if a late maturing variety will be used, the total crop cycle length (2050 late_var) is projected to remain relatively the same as for the current variety under “present” climate conditions (2000) (fig. 117);
- with respect to the four crop coefficient stages, a relative reduction is predicted in proportion to the corresponding increase in the cumulative GDD (lower during winter, higher during spring-summer months), both in the case of early (November) and late (February) sowing dates (fig. 116).

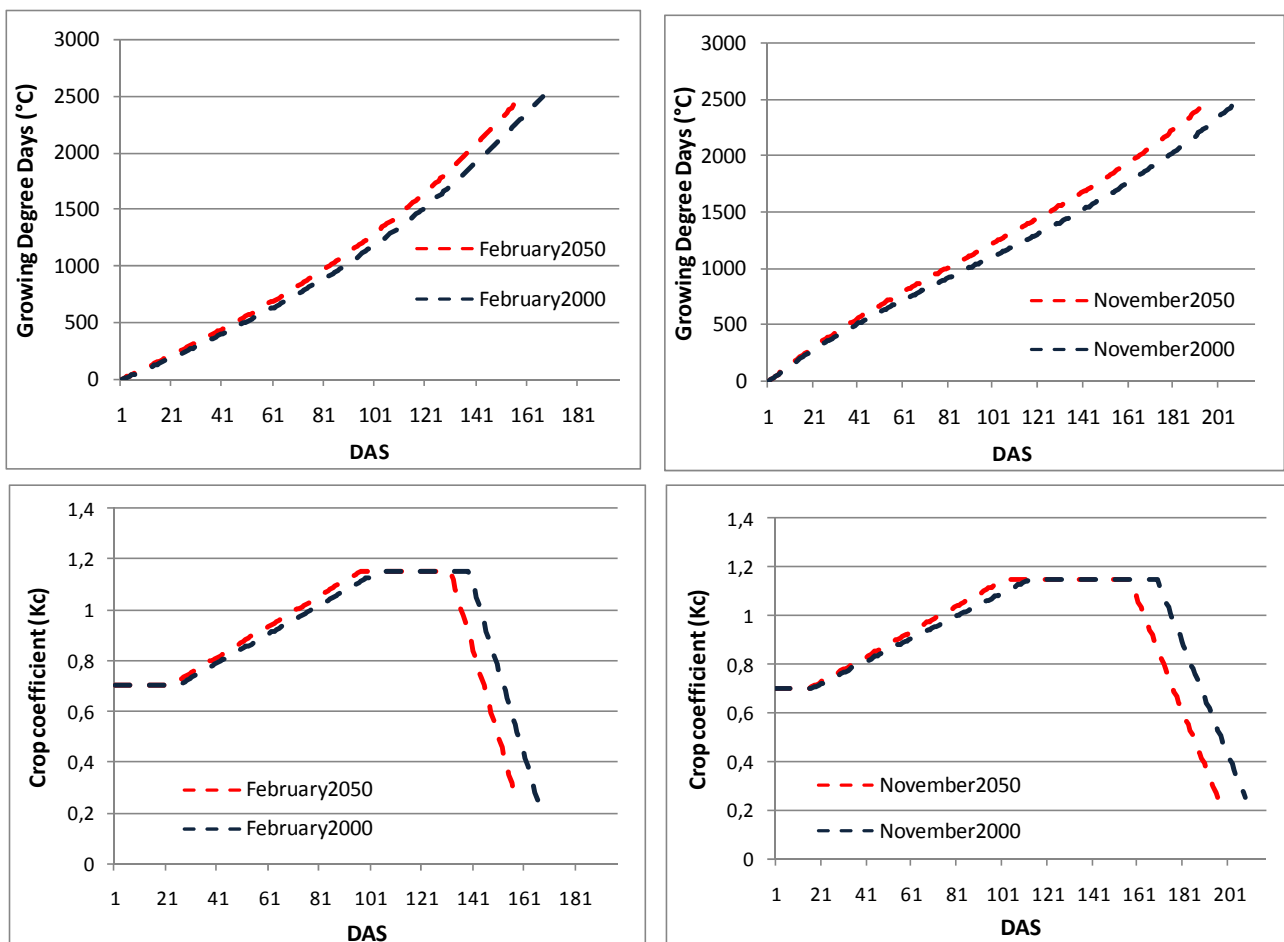


Fig. 116 – Predicted cumulative GDD and corresponding Kc curves for wheat in Sardinia Region (Italy) as affected by different planting dates and climate scenarios.

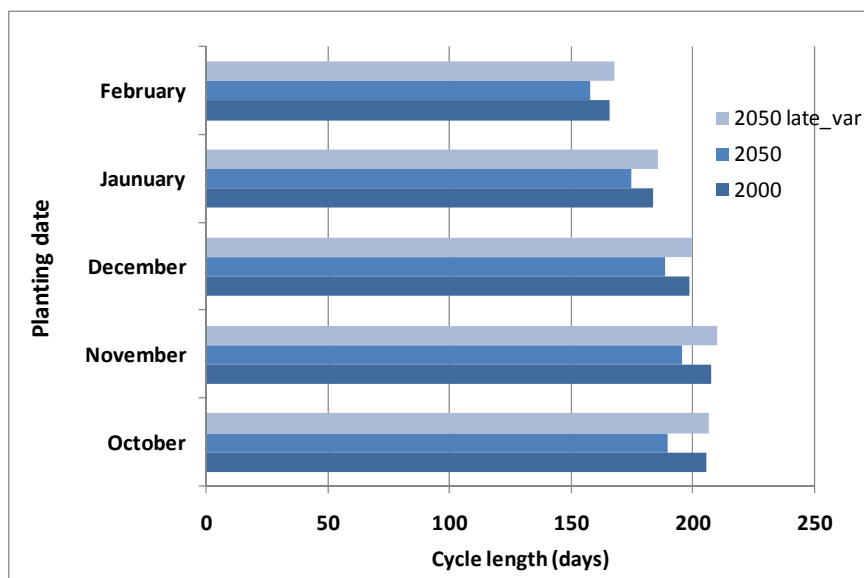


Fig. 117 – Length of total growing cycle of wheat in Sardinia Region (Italy) as affected by planting date, variety selection and climate variations.

7.2.2. Crop evapotranspiration and irrigation requirements

The impact of climate change on maximum and effective crop evapotranspiration as well as on net irrigation requirements, also considering the relative effect of selected adaptation strategies (planting dates, variety selection and deficit irrigation strategies), is summarized in the following tables and graphs. In brief, the following observations are reported:

- maximum seasonal crop evapotranspiration is projected to reduce for the current variety under “future” (2050) scenario as a consequence of the expected shortening of the crop growing cycle, on average of about -4.6% with respect to current conditions (2000) (fig. 119 and tab. 144);
- on the contrary, if a late maturing variety (2050 late_var) is selected, maximum evapotranspiration is projected to increase (on average of about +6.9%) for all the planting dates (fig. 119 and tab.144);
- the relative effect of the projected variation of rainfall patterns seems to be relevant for the crop water balance, with reduction of about 37 mm (about -12.3%) during the cropping cycle (tab.145);
- maximum seasonal crop evapotranspiration is observed always to increase (in absolute terms) for late (February) planting date with respect to earlier (October) ones, because of the shifting of most of the cycle towards the spring-summer season (fig. 119 and tab.144);
- effective seasonal crop evapotranspiration and net irrigation requirements are both highly dependent on the irrigation strategy, progressively reducing going from full irrigation to rainfed conditions (fig. 119 and tab. 146-147);
- as for ET_{c_max} , also the ET_{c_eff} and NIR are projected to decrease in 2050 if the current variety is used; on the other side, if a late maturing variety is selected, NIR is clearly projected to increase, while ET_{c_eff} variation is more dependent on the irrigation strategy considered (fig. 119 and tab. 146-147);

Tab. 144 – Effect of planting date and variety selection on the maximum crop evapotranspiration of wheat in Sardinia Region (Italy) under “present” and “future” climate conditions.

Planting date	ETc_max 2000	ETc_max 2050		ETc_max 2050 late_var	
	[mm/season]	[mm/season]	(variation vs 2000)	[mm/season]	(variation vs 2000)
october	365.9	338.4	-7.5%	386.7	5.7%
november	416.0	388.8	-6.5%	446.6	7.4%
december	467.4	443.7	-5.1%	501.3	7.2%
january	492.5	475.0	-3.6%	538.3	9.3%
february	536.3	527.9	-1.6%	584.7	9.0%
average	455.6	434.8	-4.6%	491.5	7.9%

Tab. 145 – Effect of planting date and variety selection on the effective rainfall pattern during crop cycle of wheat in Sardinia Region (Italy) under “present” and “future” climate conditions.

Planting date	Rain_eff 2000	Rain_eff 2050		Rain_eff 2050 late_var	
	[mm/season]	[mm/season]	(variation vs 2000)	[mm/season]	(variation vs 2000)
october	419.2	367.8	-12.3%	391.9	-6.5%
november	382.8	334.9	-12.5%	334.9	-12.5%
december	328.3	284.1	-13.5%	288.0	-12.3%
january	210.5	186.7	-11.3%	190.0	-9.7%
february	162.1	143.9	-11.2%	147.2	-9.2%
average	300.6	263.5	-12.3%	270.4	-10.1%

Tab. 146 – Effect of irrigation strategies and variety selection on the effective evapotranspiration of wheat in Sardinia Region (Italy) under “present” and “future” climate conditions.

Irrigation strategy	ETc_eff 2000	ETc_eff 2050		ETc_eff 2050 late_var	
	[mm/season]	[mm/season]	(variation vs 2000)	[mm/season]	(variation vs 2000)
full	455.6	434.8	-4.6%	491.5	7.9%
mild1	450.7	423.1	-6.1%	477.2	5.9%
mild2	441.4	420.8	-4.7%	469.9	6.5%
medium	428.1	387.2	-9.5%	433.1	1.2%
severe1	412.4	386.8	-6.2%	427.0	3.5%
severe2	379.3	348.6	-8.1%	378.3	-0.3%
rainfed	328.3	308.3	-6.1%	321.8	-2.0%

Tab. 147 – Effect of irrigation strategies and variety selection on the net irrigation requirements of wheat in Sardinia Region (Italy) under “present” and “future” climate conditions.

Irrigation strategy	NIR 2000	NIR 2050		NIR 2050 late_var	
	[mm/season]	[mm/season]	(variation vs 2000)	[mm/season]	(variation vs 2000)
full	186.7	178.1	-4.6%	231.1	23.8%
mild1	163.0	163.0	0.0%	196.2	20.3%
mild2	149.3	142.5	-4.6%	184.9	23.8%
medium	130.2	109.4	-16.0%	138.7	6.5%
severe1	105.9	105.9	0.0%	127.5	20.3%
severe2	65.1	54.7	-16.0%	69.4	6.5%
rainfed	0.0	0.0	0.0%	0.0	0.0%

- by plotting together the values of seasonal ETc_{eff} and NIR (obtained under different irrigation strategies and variety) for different climate scenarios, there is a clear prediction of their reduction (respectively of about -6.3% and -3.5%, on average) while, by considering a late maturing variety, an increase of both is predicted (respectively of about +3.9% and +16.7%, on average) (fig. 118);
- the cumulative curves of ETc_{max} in 2050 (versus 2000) show always (also under different planting dates) a clear shifting towards higher values, thus representing the relative increase in the daily crop water requirements, although with a decrease in the cumulative final value (depending on the anticipated ending of the cycle) (fig. 120).

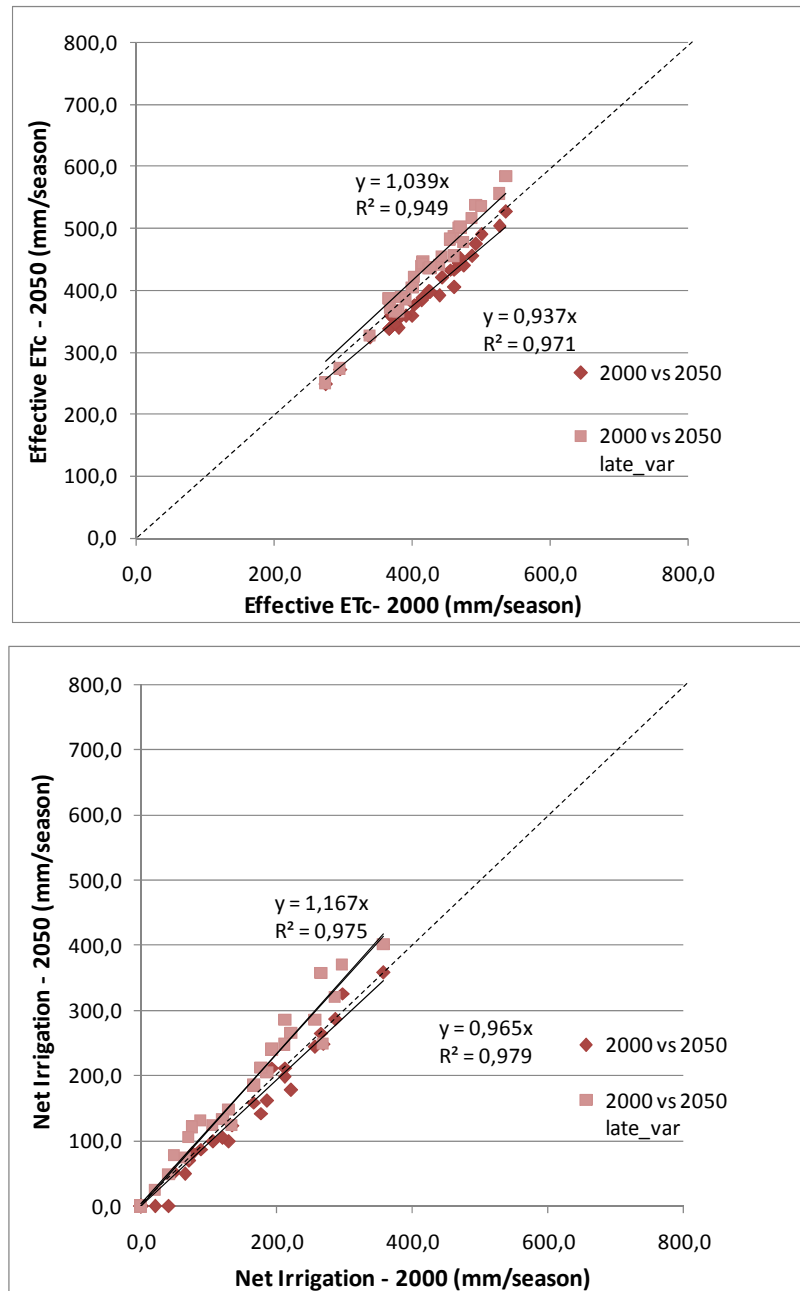


Fig. 118 – Scatter-plot of seasonal crop evapotranspiration and net irrigation requirements of as affected by different variety selection for wheat in Sardinia Region (Italy) under “present” and “future” climate conditions.

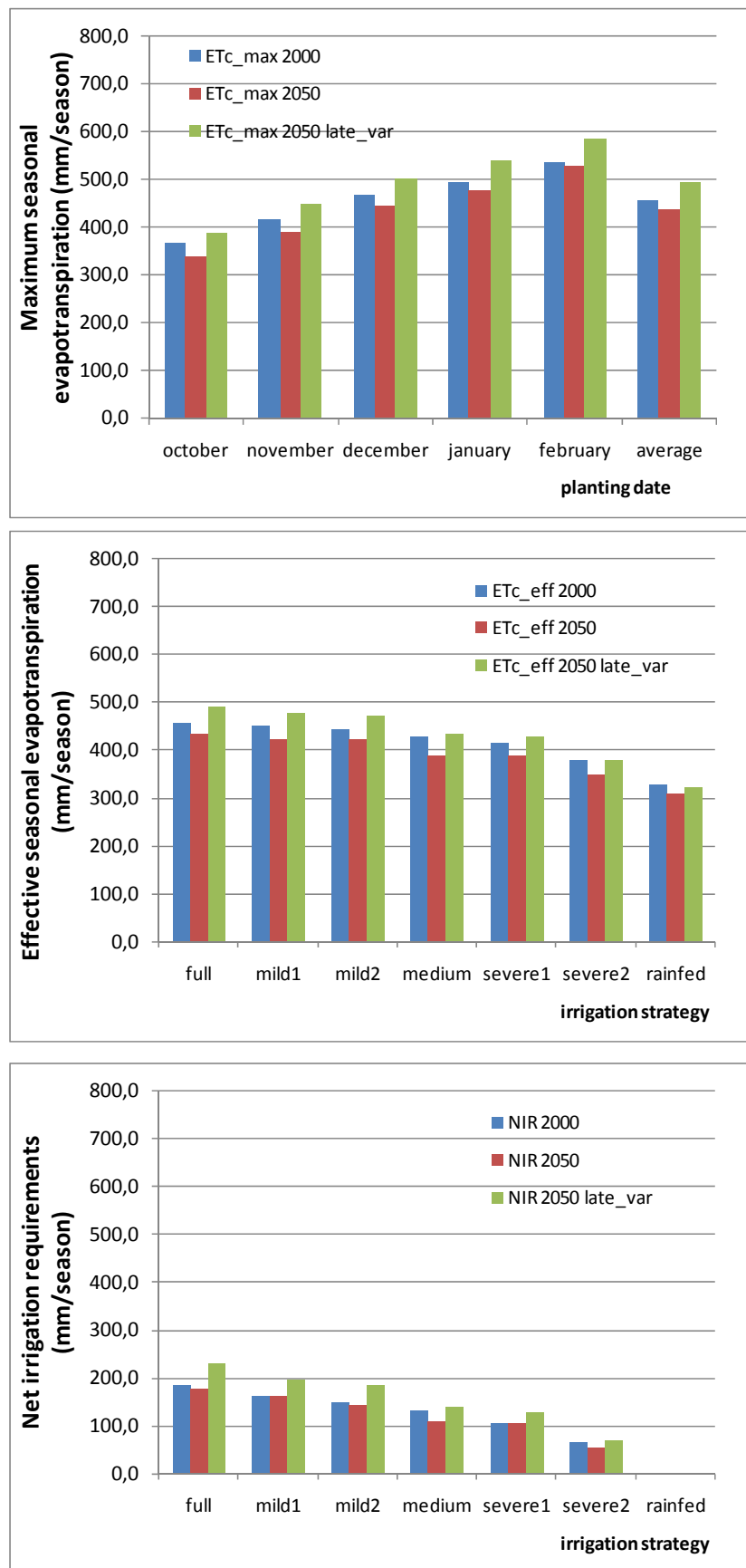


Fig. 119 – Effect of planting date, irrigation strategies and variety selection on maximum and effective crop evapotranspiration and net irrigation requirements of wheat in Sardinia Region (Italy) under “present” and “future” climate conditions.

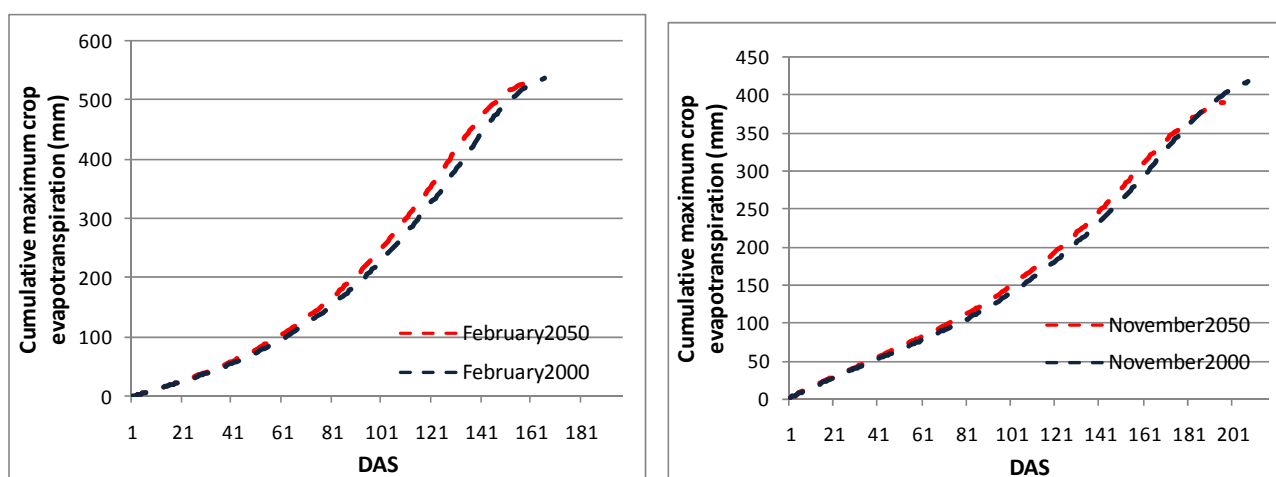


Fig. 120 – Cumulative curves of maximum crop evapotranspiration as affected by different planting date for wheat in Sardinia Region (Italy) under “present” and “future” climate conditions.

7.2.3. Crop evapotranspiration under extreme weather conditions.

If a simulated future “extreme weather” climate condition (2050+1) is considered (created by adding +1°C to daily temperature of 2050 climate scenario), the following observations on crop cycle length are reported (fig.121):

- with current variety, a further important reduction of the total growing cycle is predicted for quite all planting dates with respect to 2000 and 2050 scenario, because of the further faster accumulation of the required GDD sum;
- if a late maturing variety is considered, the total crop cycle length (2050+1 late_var) is only partly recovered with respect to present (2000) scenario only, while it is significantly shortened in all other cases with respect to 2050 late_var and 2000 scenarios.

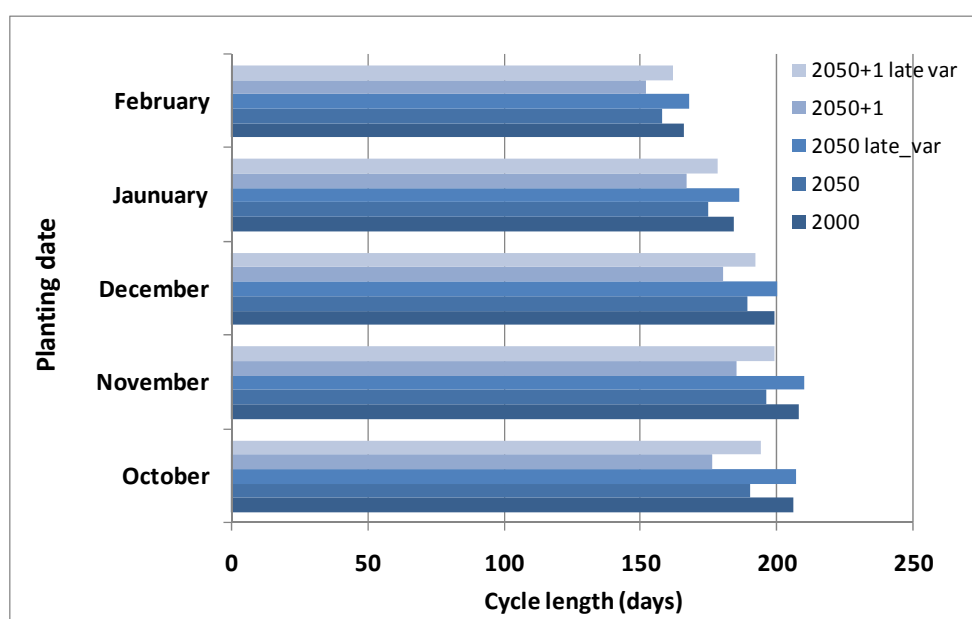


Fig. 121 – Length of total cycle length of wheat in Sardinia Region (Italy) as affected by planting date and variety selection under “present (2000)”, “future (2050)” and “future extreme weather (2050+1)” climate conditions.

The impact of future “extreme weather” conditions (2050+1) on maximum and effective crop evapotranspiration as well as on net irrigation requirements, also considering the relative effect of selected adaptation strategies (planting dates, variety selection and deficit irrigation strategies), is summarized in the following tables and graphs. In brief, the following observations are reported:

- *ETc_max* is projected to reduce for the current variety under future “extreme weather” (2050+1) scenario as a consequence of the expected further shortening of the crop growing cycle, on average of about -6.5% with respect to present conditions (2000); on the contrary, if a late maturing variety (2050+1 late_var) is selected, *ETc_max* is projected to increase (+5.6% on average) (tab. 148);
- *ETc_max* is observed always to increase (in absolute terms) for late (February) planting date with respect to earlier (October) ones, because of the shifting of most of the cycle towards the hotter spring-summer season (fig. 122 and tab.148);
- the relative effect of the projected variation of rainfall patterns (about -40%) seems to be relevant for the crop water balance, because of the reduction of about -120 mm (tab.149);
- *ETc_eff* is projected to decrease under 2050+1 scenario if the current variety is used; if a late maturing variety is selected (tab. 150), it is projected to decrease (under rainfed and severe conditions) or to increase (under better irrigated conditions), always with respect to 2000 baseline scenario;
- on the other side, *NIR* is projected to increase significantly under 2050+1 scenario, both if the current variety is used or if a late maturing variety is selected (tab.151), always with respect to 2000 baseline scenario;
- *ETc_eff* and *NIR* are both highly dependent on the irrigation strategy, progressively reducing especially from medium stress to rainfed conditions, under all climate scenarios (fig.122);
- by plotting together the values of seasonal *ETc_eff* and *NIR* for 2000 versus 2050+1 climate scenarios, there is a clear prediction of *ETc_eff* variation with current and late varieties (respectively of about -8.5% and +1.5%, on average), but, on the other side, an correspondent increase of *NIR* (respectively of about +8.2% and +29.5%, on average) (fig. 123).

Tab. 148 – Effect of planting date and variety selection on the maximum crop evapotranspiration of wheat in Sardinia Region (Italy) under “present”, “future” and “future extreme weather” climate conditions.

Planting date	ETc_max 2000	ETc_max 2050		ETc_max 2050 late_var		ETc_max 2050+1		ETc_max 2050+1 late_var	
	(mm)	(mm)	var.% (2000)	(mm)	var.% (2000)	(mm)	var.% (2000)	(mm)	var.% (2000)
october	365.9	338.4	-7.5%	386.7	5.7%	341.3	-6.7%	388.3	6.1%
november	416.0	388.8	-6.5%	446.6	7.4%	383.6	-7.8%	437.3	5.1%
december	467.4	443.7	-5.1%	501.3	7.2%	433.3	-7.3%	491.2	5.1%
january	492.5	475.0	-3.6%	538.3	9.3%	457.6	-7.1%	517.1	5.0%
february	536.3	527.9	-1.6%	584.7	9.0%	515.0	-4.0%	572.7	6.8%
average	455.6	434.8	-4.6%	491.5	7.9%	426.1	-6.5%	481.3	5.6%

Tab. 149 – Effect of planting date and variety selection on the effective rainfall pattern during crop cycle of wheat in Sardinia Region (Italy) under “present”, “future” and “future extreme weather” climate conditions.

Planting date	Rain_eff 2000	Rain_eff 2050		Rain_eff 2050 late_var		Rain_eff 2050+1		Rain_eff 2050+1 late_var	
	(mm)	[mm/season]	var.% (2000)	(mm)	var.% (2000)	(mm)	var.% (2000)	(mm)	var.% (2000)
october	419.2	367.8	-12.3%	391.9	-6.5%	243.7	-41.9%	262.1	-37.5%
november	382.8	334.9	-12.5%	334.9	-12.5%	230.6	-39.8%	234.4	-38.8%
december	328.3	284.1	-13.5%	288.0	-12.3%	196.1	-40.3%	198.8	-39.4%
january	210.5	186.7	-11.3%	190.0	-9.7%	130.7	-37.9%	130.7	-37.9%
february	162.1	143.9	-11.2%	147.2	-9.2%	98.4	-39.3%	103.0	-36.5%
average	300.6	263.5	-12.3%	270.4	-10.1%	179.9	-40.1%	185.8	-38.2%

Tab. 150 – Effect of irrigation strategies and variety selection on the effective crop evapotranspiration of wheat in Sardinia Region (Italy) under “present”, “future” and “future extreme weather” climate conditions.

Irrigation strategy	ETc_eff 2000	ETc_eff 2050		ETc_eff 2050 late_var		ETc_eff 2050+1		ETc_eff 2050+1 late_var	
	(mm)	(mm)	var.% (2000)	(mm)	var.% (2000)	(mm)	var.% (2000)	(mm)	var.% (2000)
full	455.6	434.8	-4.6%	491.5	7.9%	426.1	-6.5%	481.3	5.6%
mild1	450.7	423.1	-6.1%	477.2	5.9%	420.3	-6.7%	472.6	4.9%
mild2	441.4	420.8	-4.7%	469.9	6.5%	409.4	-7.2%	457.9	3.8%
medium	428.1	387.2	-9.5%	433.1	1.2%	391.5	-8.6%	441.6	3.2%
severe1	412.4	386.8	-6.2%	427.0	3.5%	376.5	-8.7%	413.8	0.3%
severe2	379.3	348.6	-8.1%	378.3	-0.3%	337.0	-11.2%	367.1	-3.2%
rainfed	328.3	308.3	-6.1%	321.8	-2.0%	280.5	-14.6%	289.7	-11.8%

Tab. 151 – Effect of irrigation strategies and variety selection on the net irrigation requirements of wheat in Sardinia Region (Italy) under “present”, “future” and “future extreme weather” climate conditions.

Irrigation strategy	NIR 2000	NIR 2050		NIR 2050 late_var		NIR 2050+1		NIR 2050+1 late_var	
	(mm)	(mm)	var.% (2000)	(mm)	var.% (2000)	(mm)	var.% (2000)	(mm)	var.% (2000)
full	186.7	178.1	-4.6%	231.1	23.8%	220.6	18.2%	265.9	42.5%
mild1	163.0	163.0	0.0%	196.2	20.3%	185.2	13.6%	239.9	47.2%
mild2	149.3	142.5	-4.6%	184.9	23.8%	176.5	18.2%	212.7	42.5%
medium	130.2	109.4	-16.0%	138.7	6.5%	130.5	0.2%	192.1	47.6%
severe1	105.9	105.9	0.0%	127.5	20.3%	120.4	13.6%	155.9	47.2%
severe2	65.1	54.7	-16.0%	69.4	6.5%	65.2	0.2%	96.1	47.6%
rainfed	0.0	0.0		0.0		0.0		0.0	

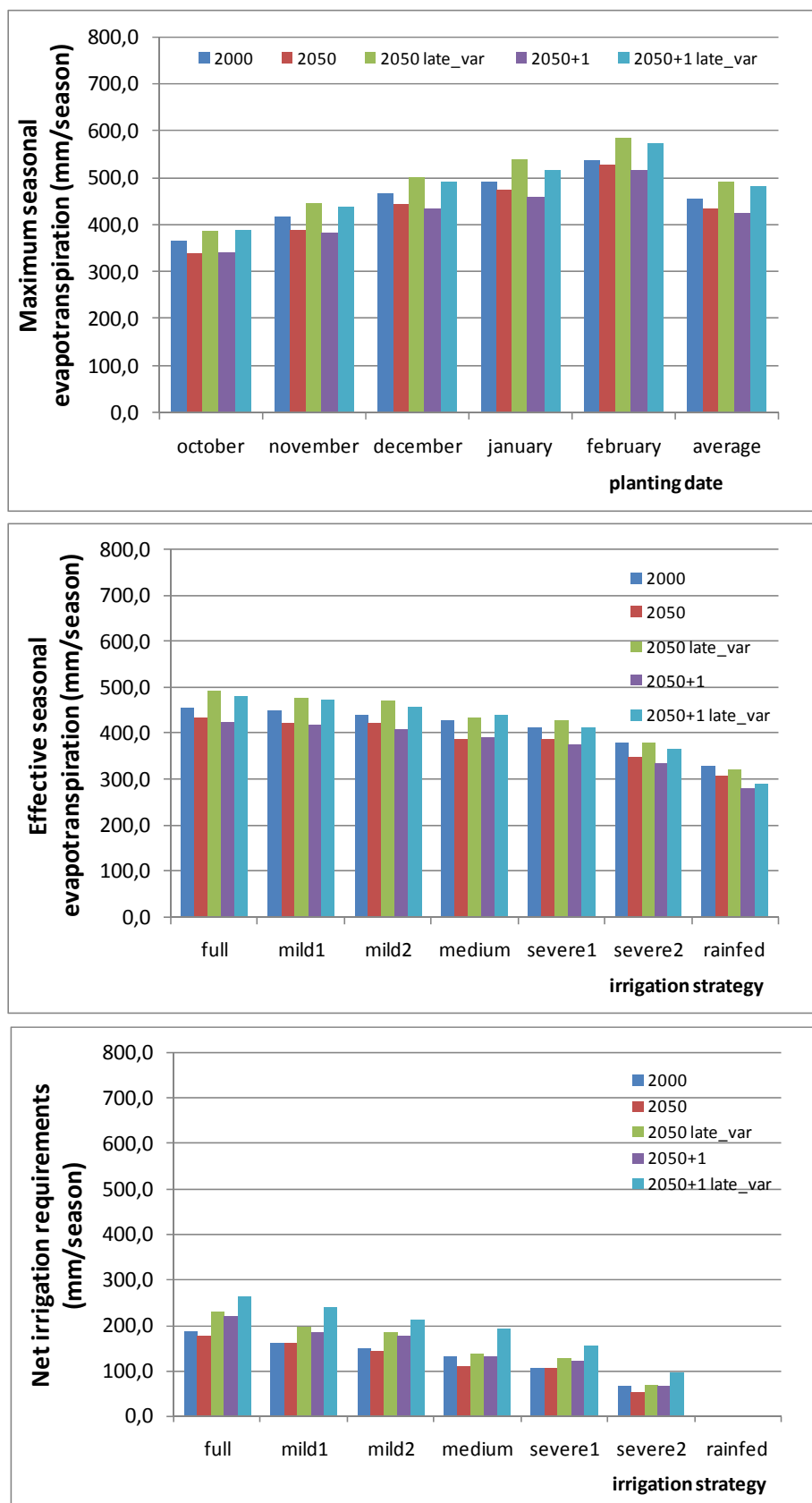


Fig. 122 – Effect of planting date, irrigation strategies and variety selection on maximum and effective crop evapotranspiration and net irrigation requirements of wheat in Sardinia Region (Italy) under “present” and “future” and “extreme weather (2050+1)” climate conditions.

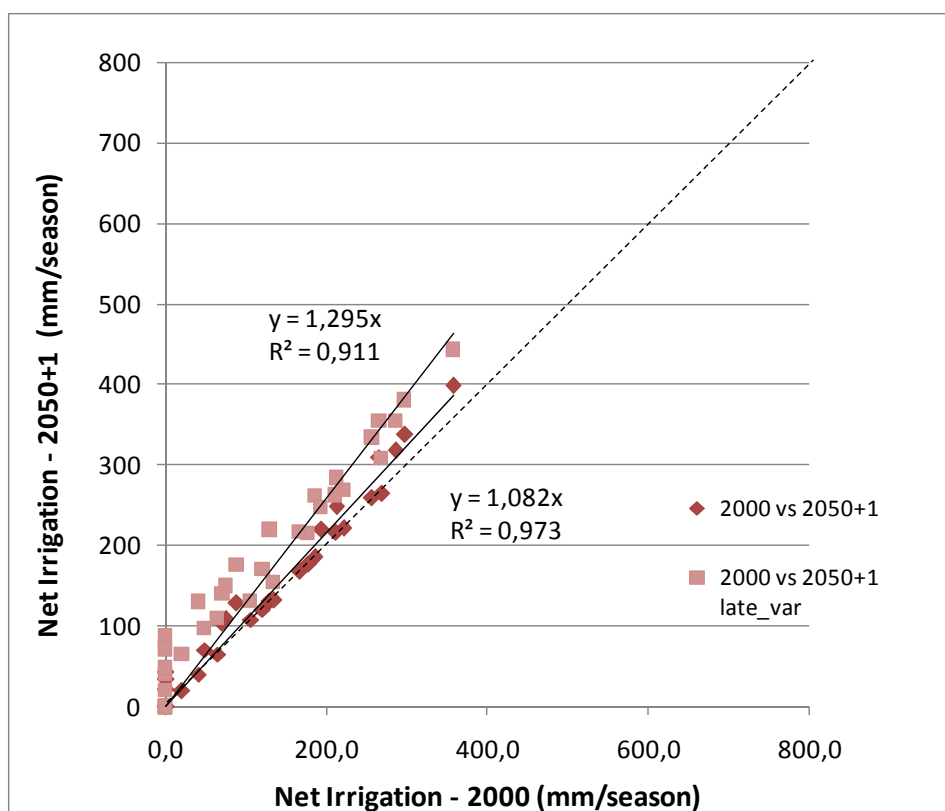
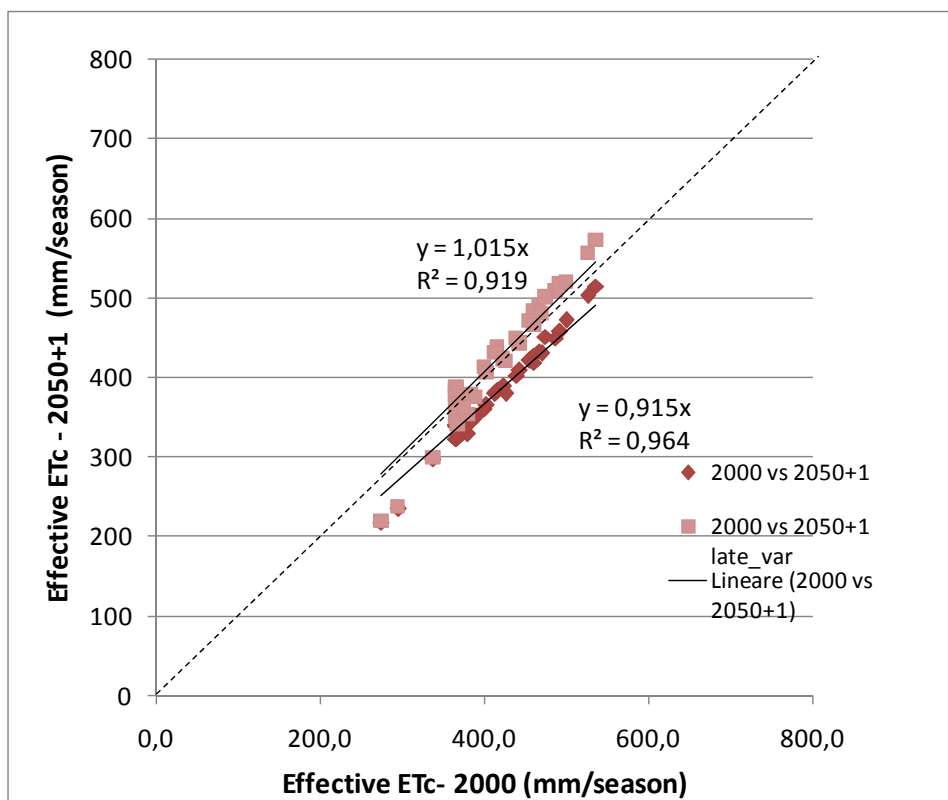


Fig. 123 – Scatter-plot of seasonal crop evapotranspiration and net irrigation requirements of as affected by different variety selection for wheat in Sardinia Region (Italy) under “present (2000)” and “future extreme weather (2050+1)” climate conditions.

7.2.4. Yield response to water

The impact of “future” climate projections (2050) and “extreme weather” (2050+1) on potential yield, also considering the relative effect of selected adaptation strategies (planting dates, variety selection and deficit irrigation strategies), is summarized in the following tables and graphs. In brief, the following observations are reported:

- potential yield is projected to reduce under “future” scenario (2050) with respect to current conditions (2000), on average from 7.3 to 7.0 t ha⁻¹ (about -4.6%), depending on irrigation strategies (tab. 152 and fig.124) and planting dates (tab. 153 and fig.124) as a consequence of the expected shortening of the crop growing cycle;
- on the contrary, if the expected fertilizing effect due to an increase in atmospheric CO₂ concentration will occur, yield is projected to increase in quite all conditions (2050 wp_adj), up to an average of 8.3 t ha⁻¹ (+14.5%), and thus to overcome the effect of the shortening of the crop cycle (fig. 124 and tab.152-153);
- on the other side, if a late maturing variety (2050 late_var) is selected, yield is projected to increase up to an average of 7.9 t ha⁻¹ (+7.9%), especially under fully irrigation (fig. 124 and tab.152-153);
- if “extreme weather” conditions (2050+1) are considered, the average expected yield reduction (down to 6.8 t ha⁻¹, -6.5%) is greater than in 2050 scenario, but also in this case it could be completely recovered because of the CO₂ fertilizing effect or the late-variety selection, respectively to 8.2 t ha⁻¹ (+12.2%) and 7.7 t ha⁻¹ (+5.6%);
- with respect to irrigation strategies, there is a clear reduction in potential yield under increasing water stress conditions (fig.124), but still under “severe” water stress (thus only supported by supplemental irrigations) values up to 5-6.5 t ha⁻¹ are expected, while under rainfed conditions, an average yield of 4 t ha⁻¹ is still predicted in all climate conditions;
- yield is observed always to increase (in absolute terms) for late (February) planting date with respect to earlier (October) ones (fig.124), but a corresponding increase in crop water requirements is clearly projected (as it has been highlighted in the previous paragraph).

Tab. 152 – Effect of irrigation strategies, variety selection and atmospheric CO₂ increase on the potential yield of wheat in Sardinia Region (Italy) under “present”, “future” and “extreme weather” climate conditions.

Irrigation strategy	Yield 2000 (*)	Yield 2050 (*)		Yield 2050 wp_adj (**)		Yield 2050 late_var (*)		Yield 2050+1 (*)		Yield 2050+1 wp_adj (**)		Yield 2050+1 late_var (*)	
		(t/ha)	var.% (2000)	(t/ha)	var.% (2000)	(t/ha)	var.% (2000)	(t/ha)	var.% (2000)	(t/ha)	var.% (2000)	(t/ha)	var.% (2000)
full	7.3	7.0	-4.6%	8.3	14.5%	7.9	7.9%	6.8	-6.5%	8.2	12.2%	7.7	5.6%
mild1	7.2	6.7	-6.7%	8.0	12.0%	7.6	5.1%	6.7	-6.8%	8.0	11.9%	7.5	4.6%
mild2	7.0	6.7	-4.5%	8.0	14.6%	7.4	6.1%	6.5	-7.4%	7.7	11.1%	7.2	3.1%
medium	6.7	6.0	-11.0%	7.2	6.8%	6.6	-1.1%	6.1	-9.4%	7.3	8.7%	6.9	2.5%
severe1	6.4	6.0	-6.1%	7.2	12.6%	6.5	2.6%	5.8	-9.1%	6.9	9.1%	6.3	-1.1%
severe2	5.7	5.3	-8.0%	6.3	10.4%	5.6	-1.6%	5.0	-12.1%	6.0	5.4%	5.4	-5.1%
rainfed	4.8	4.6	-4.0%	5.6	15.3%	4.7	-1.6%	4.1	-14.9%	4.9	2.1%	4.1	-13.9%
(*) assuming wp (2000) = 1.6 (kg/m3)													
(**) assuming wp (2050)= wp(2000)*1.2= 1.92 (kg/m3)													

Tab. 153 – Effect of planting date, variety selection and atmospheric CO₂ increase on the potential yield of wheat in Sardinia Region (Italy) under “present”, “future” and “extreme weather” climate conditions.

Irrigation strategy	Yield 2000 (*)	Yield 2050 (*)		Yield 2050 wp_adj (**)		Yield 2050 late_var (*)		Yield 2050+1 (*)		Yield 2050+1 wp_adj (**)		Yield 2050+1 late_var (*)	
		(t/ha)	var.% (2000)	(t/ha)	var.% (2000)	(t/ha)	var.% (2000)	(t/ha)	var.% (2000)	(t/ha)	var.% (2000)	(t/ha)	var.% (2000)
october	5.9	5.4	-7.5%	6.5	11.0%	6.2	5.7%	5.5	-6.7%	6.6	11.9%	6.2	6.1%
november	6.7	6.2	-6.5%	7.5	12.2%	7.1	7.4%	6.1	-7.8%	7.4	10.7%	7.0	5.1%
december	7.5	7.1	-5.1%	8.5	13.9%	8.0	7.2%	6.9	-7.3%	8.3	11.2%	7.9	5.1%
january	7.9	7.6	-3.6%	9.1	15.7%	8.6	9.3%	7.3	-7.1%	8.8	11.5%	8.3	5.0%
february	8.6	8.4	-1.6%	10.1	18.1%	9.4	9.0%	8.2	-4.0%	9.9	15.2%	9.2	6.8%
average	7.3	7.0	-4.6%	8.3	14.5%	7.9	7.9%	6.8	-6.5%	8.2	12.2%	7.7	5.6%
(*) assuming wp (2000) = 1.6 (kg/m3)													
(**) assuming wp (2050)= wp(2000)*1.2= 1.92 (kg/m3)													

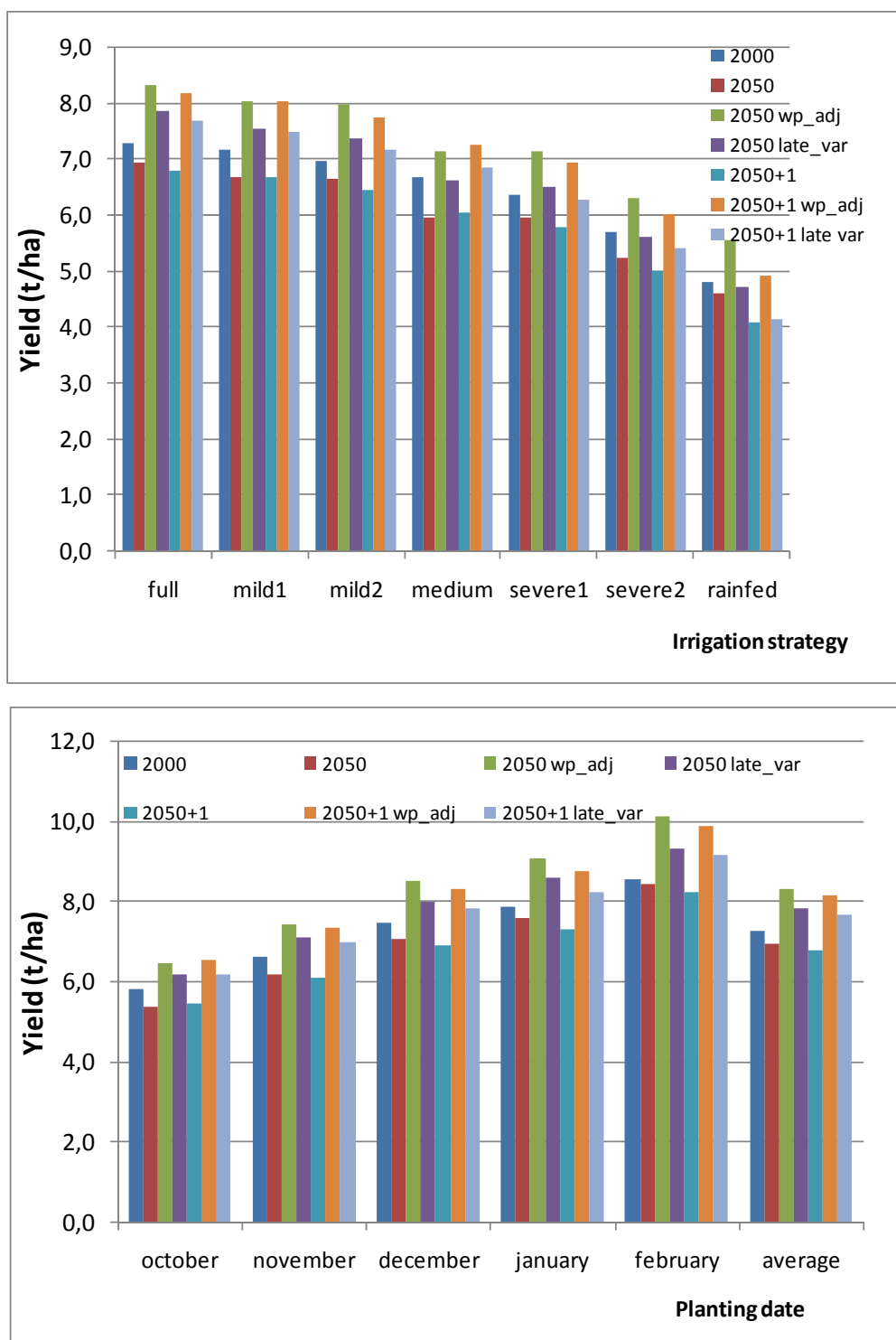


Fig. 124 – Effect of planting date, irrigation strategies, variety selection and atmospheric CO₂ increase on potential yield of wheat in Sardinia Region (Italy) under “present”, “future” and “extreme weather (2050+1)” climate conditions.

7.3. Tomato

7.3.1. Cycle length and crop coefficient curves

The effect of temperature increase (and relative GDD accumulation) on current and projected crop cycle length and corresponding crop coefficient curves is represented in the following graphs, and the following observations have to be highlighted:

- if varietal adaptation is not considered, an important reduction of the total growing cycle is predicted for all planting dates, because of the faster accumulation of the required GGD sum under “future” climate conditions (2050) (fig. 125-126);
- if a late maturing variety will be used, the total crop cycle length (2050 late_var) is projected to remain relatively the same as for the current variety under “present” climate conditions (2000), especially for late planting dates (fig. 126);
- with respect to the four crop coefficient stages, a relative reduction is predicted in proportion to the corresponding increase in the cumulative GDD (lower during winter, higher during spring-summer months), but with a greater effect in the case of early (March) rather than late (May) planting dates (fig. 125).

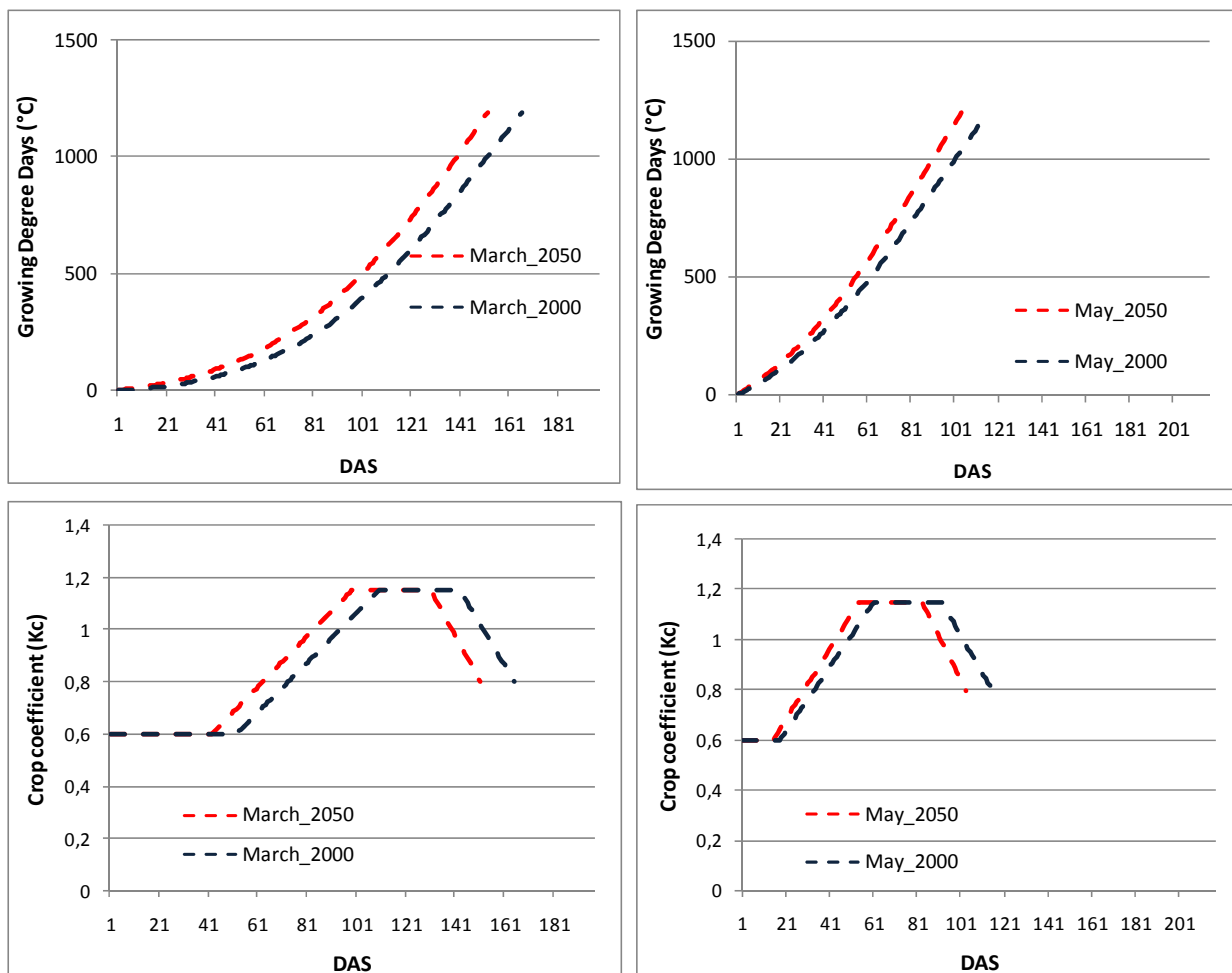


Fig. 125 – Predicted cumulative GDD and corresponding Kc curves for tomato in Sardinia Region (Italy) as affected by different planting dates and climate scenarios.

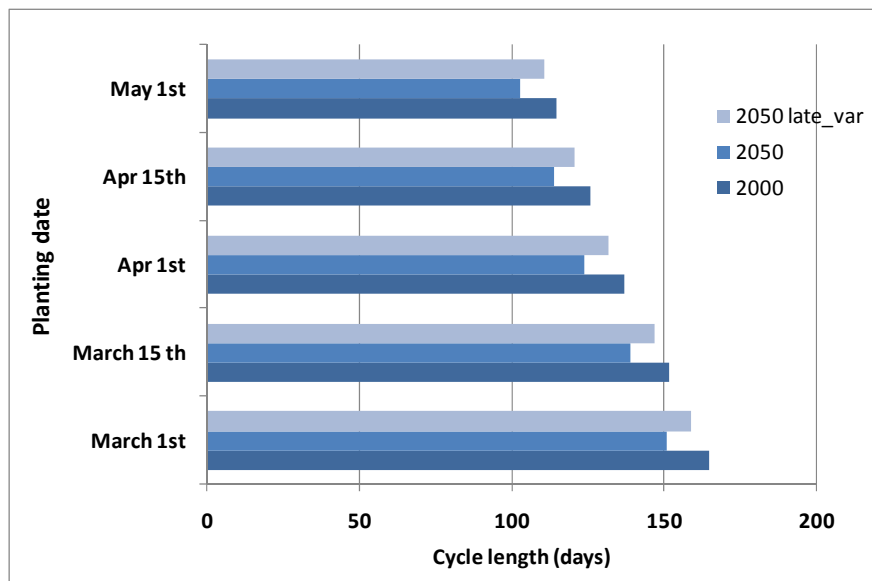


Fig. 126 – Length of total growing cycle of tomato in Sardinia Region (Italy) as affected by planting date, variety selection and climate variations.

7.3.2. Crop evapotranspiration and irrigation requirements

The impact of climate change on maximum and effective crop evapotranspiration as well as on net irrigation requirements, also considering the relative effect of selected adaptation strategies (planting dates, variety selection and deficit irrigation strategies), is summarized in the following tables and graphs. In brief, the following observations are reported:

- maximum seasonal crop evapotranspiration is projected to reduce for the current variety under “future” (2050) scenario as a consequence of the expected shortening of the crop growing cycle, on average of about -4.1% with respect to current conditions (2000) (fig.128 and tab.154);
- on the contrary, if a late maturing variety (2050 late_var) is selected, maximum evapotranspiration is projected to increase for all the planting dates (on average of about +3.1%) (fig. 128 and tab.154);
- the relative effect of the projected variation of rainfall patterns seems slightly important for the crop water balance, with an average reduction of about -24.5 mm during cropping cycle (tab.155);
- maximum seasonal crop evapotranspiration is observed always to decrease slightly (in absolute terms) for late (May) planting date with respect to earlier (March) ones, because of the shifting of the cycle towards the higher summer temperatures and the corresponding reduction in the total length (fig.128 and tab.154);
- effective seasonal crop evapotranspiration and net irrigation requirements are both highly dependent on the irrigation strategy, progressively reducing going from full irrigation to rainfed conditions (fig. 128 and tab.156-157);
- as for ET_{c_max} , also the ET_{c_eff} and NIR are projected to decrease in 2050 if the current variety is used; on the other side, if a late maturing variety is selected, NIR and ET_{c_eff} are always projected to increase (fig. 128 and tab.156-57);

Tab. 154 – Effect of planting date and variety selection on the maximum crop evapotranspiration of tomato in Sardinia Region (Italy) under “present” and “future” climate conditions.

Planting date	ETc_max 2000	ETc_max 2050		ETc_max 2050 late_var	
	[mm/season]	[mm/season]	(variation vs 2000)	[mm/season]	(variation vs 2000)
March 1st	634.8	609.8	-3.9%	653.6	3.0%
March 15th	618.6	595.8	-3.7%	640.2	3.5%
Apr 1st	596.9	569.0	-4.7%	613.9	2.9%
Apr 15th	578.8	555.4	-4.0%	593.7	2.6%
May 1st	555.9	533.1	-4.1%	576.8	3.8%
Average	597.0	572.6	-4.1%	615.6	3.1%

Tab. 155 – Effect of planting date and variety selection on the effective rainfall pattern during crop cycle of tomato in Sardinia Region (Italy) under “present” and “future” climate conditions.

Planting date	Rain_eff 2000	Rain_eff 2050		Rain_eff 2050 late_var	
	[mm/season]	[mm/season]	(variation vs 2000)	[mm/season]	(variation vs 2000)
March 1st	137.5	111.3	-19.1%	114.6	-16.6%
March 15th	103.4	78.8	-23.7%	82.2	-20.5%
Apr 1st	76.3	52.6	-31.0%	55.9	-26.7%
Apr 15th	61.7	42.8	-30.6%	46.2	-25.2%
May 1st	55.8	26.4	-52.7%	35.0	-37.4%
average	86.9	62.4	-28.2%	66.8	-23.2%

Tab. 156 – Effect of irrigation strategies and variety selection on the effective evapotranspiration of tomato in Sardinia Region (Italy) under “present” and “future” climate conditions.

Irrigation strategy	ETc_eff 2000	ETc_eff 2050		ETc_eff 2050 late_var	
	[mm/season]	[mm/season]	(variation vs 2000)	[mm/season]	(variation vs 2000)
full	597.0	572.6	-4.1%	615.6	3.1%
mild1	578.5	551.1	-4.7%	591.6	2.3%
mild2	530.2	506.6	-4.5%	542.0	2.2%
medium	522.1	489.1	-6.3%	525.5	0.7%
severe1	448.2	423.2	-5.6%	450.4	0.5%
severe2	360.4	333.9	-7.3%	353.2	-2.0%
rainfed	196.6	177.5	-9.7%	179.5	-8.7%

Tab. 157 – Effect of irrigation strategies and variety selection on the net irrigation requirements of tomato in Sardinia Region (Italy) under “present” and “future” climate conditions.

Irrigation strategy	NIR 2000	NIR 2050		NIR 2050 late_var	
	[mm/season]	[mm/season]	(variation vs 2000)	[mm/season]	(variation vs 2000)
full	494.5	493.5	-0.2%	528.2	6.8%
mild1	461.5	438.8	-4.9%	479.3	3.9%
mild2	395.6	394.8	-0.2%	422.6	6.8%
medium	393.8	384.9	-2.3%	408.1	3.6%
severe1	300.0	285.2	-4.9%	311.6	3.9%
severe2	196.9	192.5	-2.3%	204.1	3.6%
rainfed	0.0	0.0	0.0%	0.0	0.0%

- by plotting together the values of seasonal ETc_{eff} and NIR (obtained under different irrigation strategies and variety) for different climate scenarios, there is a clear prediction of their reduction (respectively of about -5.3% and -2.4%, on average) while, by considering a late maturing variety, only a slight increase of both is predicted (respectively of about +1.3% and +5%, on average) (fig.127);
- the cumulative curves of ETc_{max} in 2050 (versus 2000) show always (especially for earlier planting dates) a clear shifting towards higher values, thus representing the relative increase in the daily crop water requirements, although with a decrease in the cumulative final value (depending on the anticipated ending of the cycle) (fig.129).

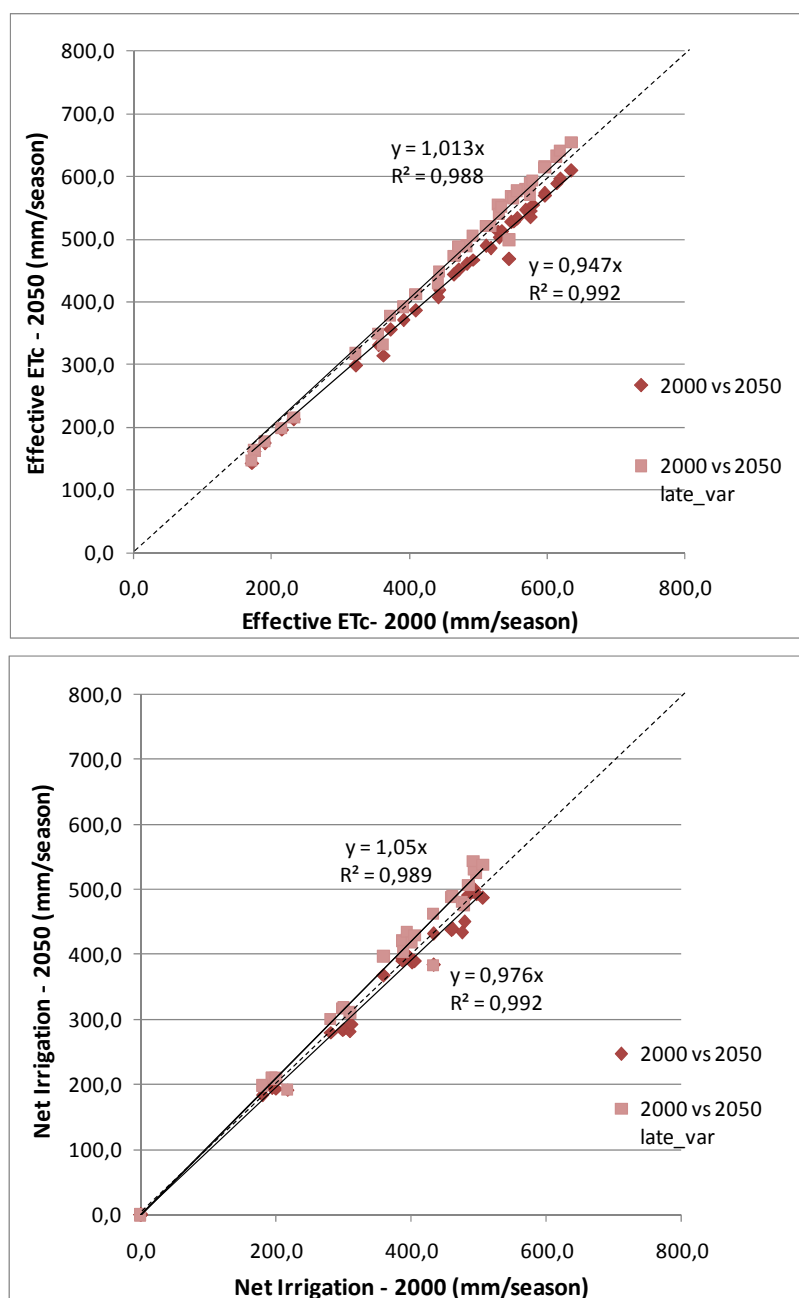


Fig. 127 – Scatter-plot of seasonal crop evapotranspiration and net irrigation requirements of as affected by different variety selection for tomato in Sardinia Region (Italy) under “present” and “future” climate conditions.

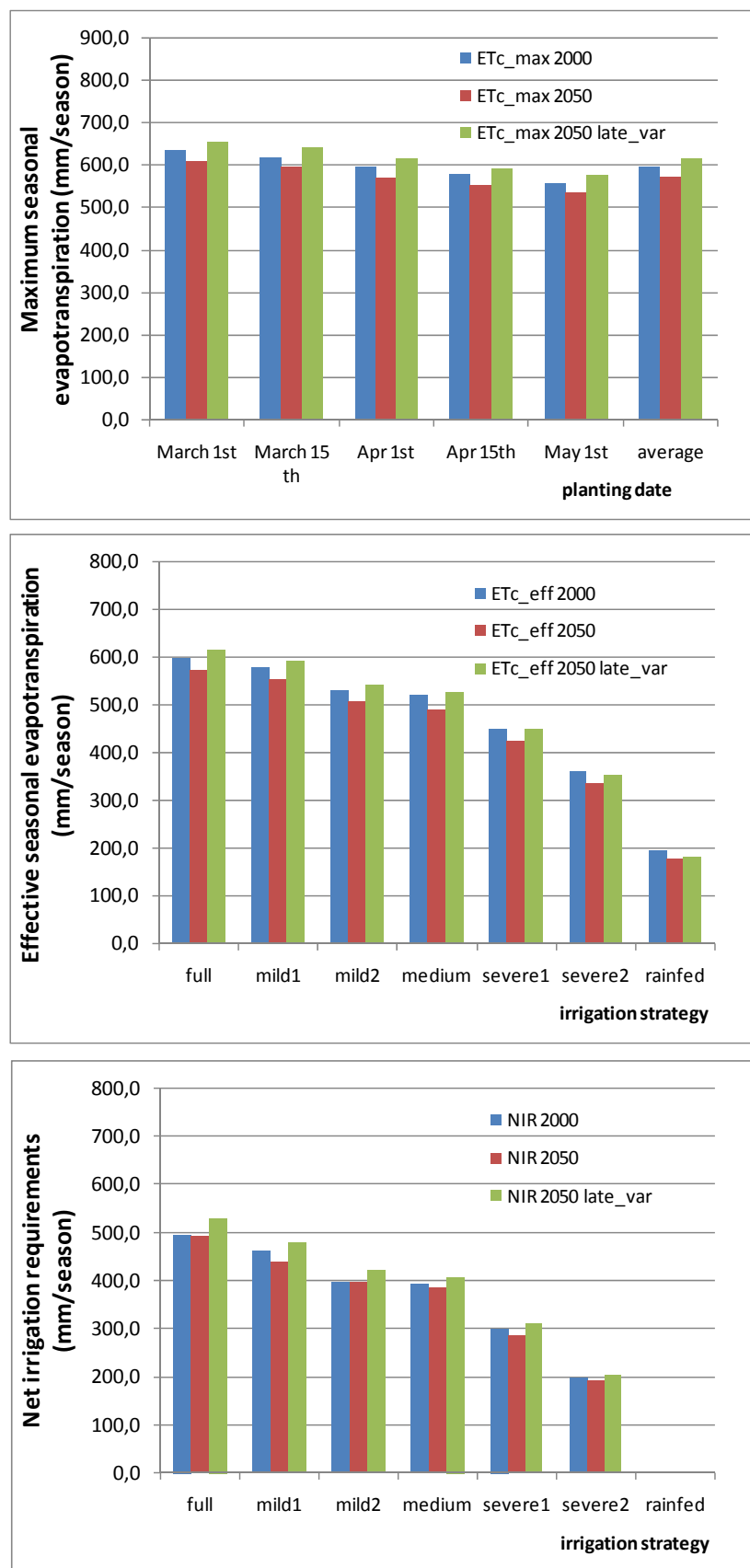


Fig. 128 – Effect of planting date, irrigation strategies and variety selection on maximum and effective crop evapotranspiration and net irrigation requirements of tomato in Sardinia Region (Italy) under “present” and “future” climate conditions.

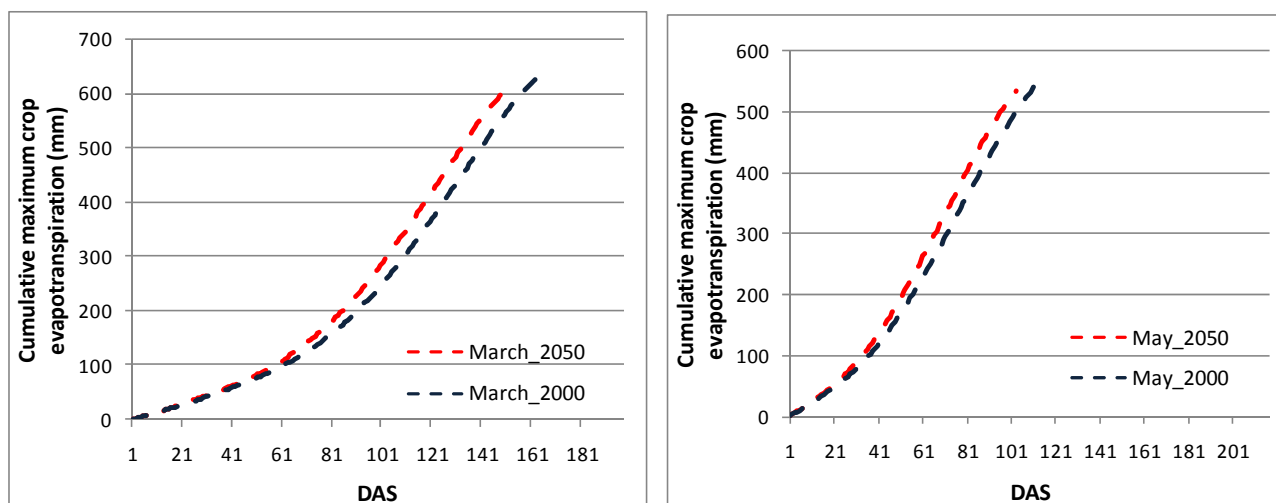


Fig. 129 – Cumulative curves of maximum crop evapotranspiration as affected by different planting date for tomato in Sardinia Region (Italy) under “present” and “future” climate conditions.

7.3.3. Yield response to water

The impact of climate change on potential yield, also considering the relative effect of selected adaptation strategies (planting dates, variety selection and deficit irrigation strategies), is summarized in the following tables and graphs. In brief, the following observations are reported:

- yield is projected to reduce under “future” scenario (2050) with respect to current conditions (2000), on average from 77.6 to 74.4 t ha⁻¹ (about -4.1%), depending on irrigation strategies (tab. 158 and fig.130) and planting dates (tab. 159 and fig.130) as a consequence of the expected shortening of the crop growing cycle;
- on the contrary, if the expected fertilizing effect due to an increase in atmospheric CO₂ concentration will occur, yield (2050 wp_adj) is projected to increase in quite all conditions (with an average of 89.3 t ha⁻¹, +15.1%), and thus to overcome the effect of the shortening of the crop cycle (fig. 130 and tab. 158-159);
- on the other side, if a late maturing variety (2050 late_var) is selected, yield is projected to increase (with an average of 80.0 t ha⁻¹, +3.1%), especially under fully irrigation and late planting dates (fig. 130 and tab. 158-159);
- there is a clear reduction in potential yield under increasing water stress conditions (fig.130), and under “severe” water stress (thus only supported by supplemental irrigations) values of 20-40 t ha⁻¹ are predicted;
- in the case of rainfed conditions, according to the model used, no yield is expected in all conditions;
- yield is observed always to slightly decrease (in absolute terms) for late (May) planting date with respect to earlier (March) ones (fig.130), because of the shortening of the growing cycle due to its shifting in the hotter summer.

Tab. 158 – Effect of irrigation strategies, variety selection and atmospheric CO₂ increase on the potential yield of tomato in Sardinia Region (Italy) under “present” and “future” climate conditions.

Irrigation strategy	Yield 2000 (*) (t/ha)	Yield 2050 (*)		Yield 2050 wp_adj (**)		Yield 2050 late_var (*)	
		(t/ha)	(variation vs 2000)	(t/ha)	(variation vs 2000)	(t/ha)	(variation vs 2000)
full	77.6	74.4	-4.1%	89.3	15.1%	80.0	3.1%
mild1	72.5	68.6	-5.5%	82.3	13.4%	73.5	1.4%
mild2	55.0	52.5	-4.4%	63.0	14.7%	56.0	1.9%
medium	58.9	54.1	-8.1%	64.9	10.2%	57.9	-1.6%
severe1	36.0	34.0	-5.6%	40.7	13.2%	36.0	-0.1%
severe2	20.4	18.9	-7.1%	22.7	11.5%	19.8	-2.8%
rainfed	0.0	0.0		0.0		0.0	
(*) assuming wp (2000) = 13 (kg/m3)							
(**) assuming wp (2050)= wp(2000)*1.2= 15.6 (kg/m3)							

Tab. 159 – Effect of planting date, variety selection and atmospheric CO₂ increase on the potential yield of tomato in Sardinia Region (Italy) under “present” and “future” climate conditions.

Irrigation strategy	Yield 2000 (*) (t/ha)	Yield 2050 (*)		Yield 2050 wp_adj (**)		Yield 2050 late_var (*)	
		(t/ha)	(variation vs 2000)	(t/ha)	(variation vs 2000)	(t/ha)	(variation vs 2000)
March 1st	82.5	79.3	-3.9%	95.1	15.3%	85.0	3.0%
March 15 th	80.4	77.5	-3.7%	92.9	15.6%	83.2	3.5%
Apr 1st	77.6	74.0	-4.7%	88.8	14.4%	79.8	2.9%
Apr 15th	75.2	72.2	-4.0%	86.6	15.1%	77.2	2.6%
May 1st	72.3	69.3	-4.1%	83.2	15.1%	75.0	3.8%
average	77.6	74.4	-4.1%	89.3	15.1%	80.0	3.1%
(*) assuming wp (2000) = 13 (kg/m3)							
(**) assuming wp (2050)= wp(2000)*1.2= 15.6 (kg/m3)							

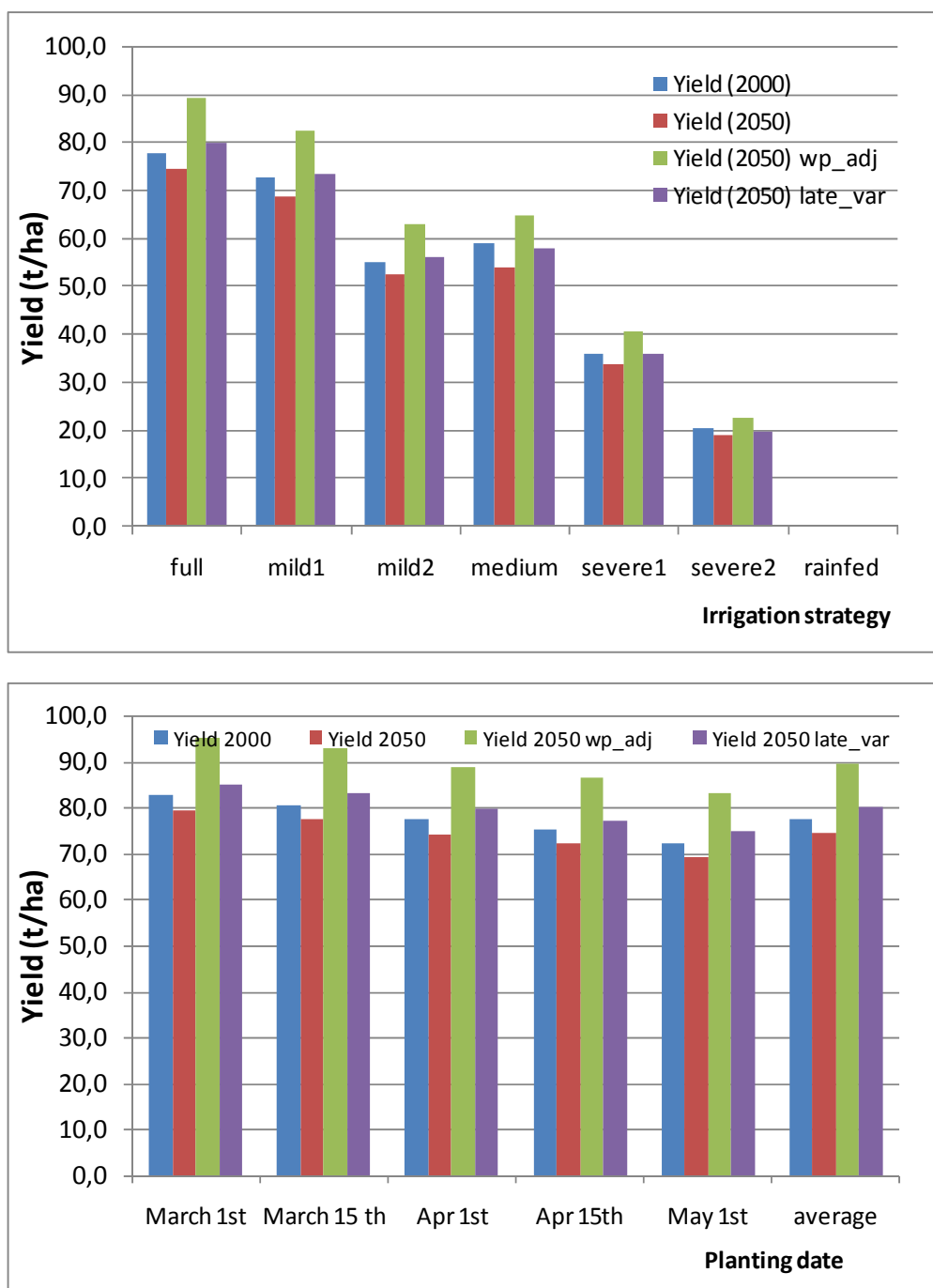


Fig. 130 – Effect of planting date, irrigation strategies, variety selection and atmospheric CO₂ increase on potential yield of tomato in Sardinia Region (Italy) under “present” and “future” climate conditions.

7.4. Maize

7.4.1. Cycle length and crop coefficient curves

The effect of temperature increase (and relative GDD accumulation) on current and projected crop cycle length and corresponding crop coefficient curves is represented in the following graphs, and the following observations have to be highlighted:

- if varietal adaptation is not considered, an important reduction of the total growing cycle is predicted for all planting dates, because of the faster accumulation of the required GDD sum under “future” climate conditions (2050) (fig. 131-132);
- also if a late maturing variety will be used, the total crop cycle length (2050 late_var) is projected to slightly reduce with respect for the current variety under “present” climate conditions (2000), especially for early planting dates (March) (fig. 132);
- with respect to the four crop coefficient stages, a relative reduction is predicted in proportion to the corresponding increase in the cumulative GDD, with a relatively greater effect in the case of early (March) rather than late (May) planting dates (fig. 131).

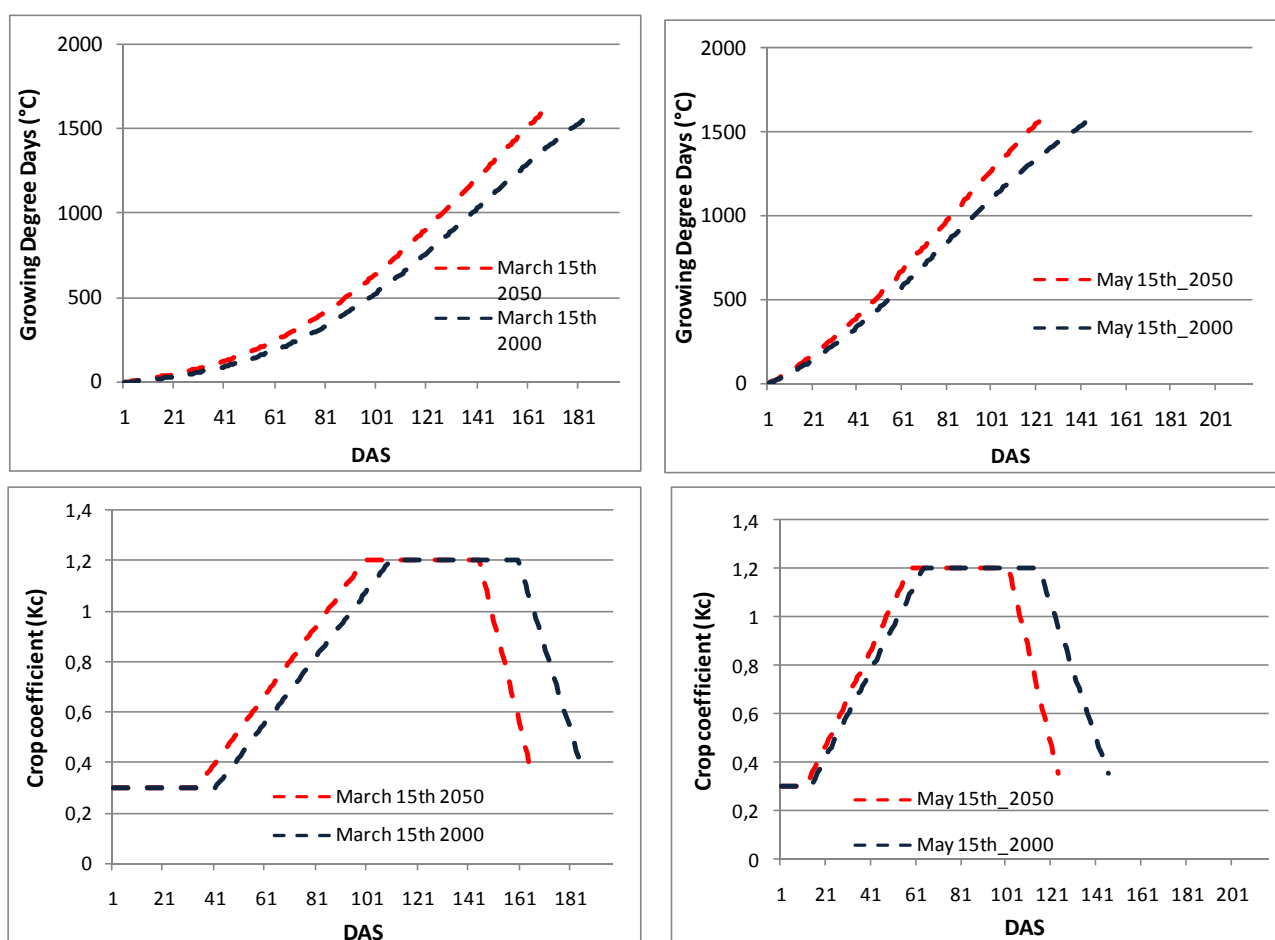


Fig. 131 – Predicted cumulative GDD and corresponding Kc curves for maize in Sardinia Region (Italy) as affected by different planting dates and climate scenarios.

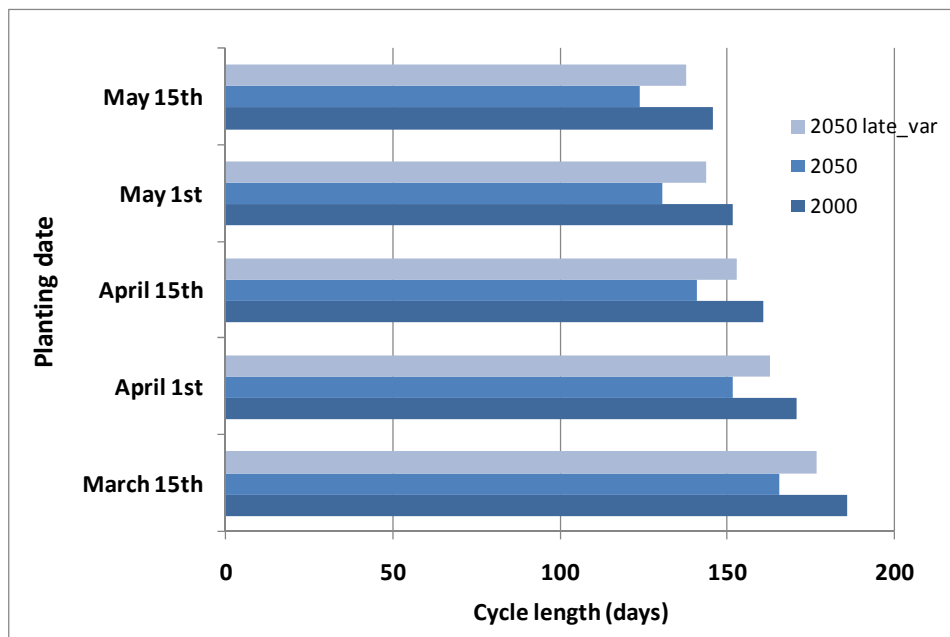


Fig. 132– Length of total growing cycle of maize in Sardinia Region (Italy) as affected by planting date, variety selection and climate variations.

7.4.2. Crop evapotranspiration and irrigation requirements

The impact of climate change on maximum and effective crop evapotranspiration as well as on net irrigation requirements, also considering the relative effect of selected adaptation strategies (planting dates, variety selection and deficit irrigation strategies), is summarized in the following tables and graphs. In brief, the following observations are reported:

- maximum seasonal crop evapotranspiration is projected to reduce for the current variety under “future” (2050) scenario as a consequence of the expected shortening of the crop growing cycle, on average of about -4.2% with respect to current conditions (2000) (fig. 134 and tab.160);
- on the contrary, if a late maturing variety (2050 late_var) is selected, maximum evapotranspiration is projected to increase (on average of about 3.2%) (fig.134 and tab.160);
- the rainfall patterns is projected to decrease of about 22 mm (tab.161);
- maximum seasonal crop evapotranspiration is observed always to increase (in absolute terms) for earlier planting dates (March) with respect to later ones, probably because of the longer growing cycle (fig. 134 and tab.160);
- effective seasonal crop evapotranspiration and net irrigation requirements are both highly dependent on the irrigation strategy, progressively reducing going from full irrigation to rainfed conditions (fig. 134 and tab.162-163);
- as for ET_{c_max} , also the ET_{c_eff} and NIR are projected to decrease in 2050 if the current variety is used; on the other side, if a late maturing variety is selected, both are projected to increase (fig. 134 and tab.162-163);

Tab.160 – Effect of planting date and variety selection on the maximum crop evapotranspiration of maize in Sardinia Region (Italy) under “present” and “future” climate conditions.

Planting date	ETc_max 2000	ETc_max 2050		ETc_max 2050 late_var	
	[mm/season]	[mm/season]	(variation vs 2000)	[mm/season]	(variation vs 2000)
March 15th	713.0	686.5	-3.7%	736.4	3.3%
April 1st	695.1	670.7	-3.5%	718.4	3.4%
April 15th	681.0	651.7	-4.3%	700.6	2.9%
May 1st	660.4	628.9	-4.8%	681.6	3.2%
May 15th	641.9	611.4	-4.7%	661.8	3.1%
average	678.3	649.9	-4.2%	699.8	3.2%

Tab. 161 – Effect of planting date and variety selection on the effective rainfall pattern during crop cycle of maize in Sardinia Region (Italy) under “present” and “future” climate conditions.

Planting date	Rain_eff 2000	Rain_eff 2050		Rain_eff 2050 late_var	
	[mm/season]	[mm/season]	(variation vs 2000)	[mm/season]	(variation vs 2000)
March 15th	132.2	101.2	-23.5%	106.5	-19.5%
April 1st	105.1	75.0	-28.7%	80.2	-23.7%
April 15th	84.8	61.9	-27.0%	72.4	-14.6%
May 1st	98.2	50.7	-48.3%	69.7	-29.0%
May 15th	100.3	50.5	-49.7%	77.9	-22.3%
average	104.1	67.9	-34.8%	81.3	-21.9%

Tab. 162 – Effect of irrigation strategies and variety selection on the effective evapotranspiration of maize in Sardinia Region (Italy) under “present” and “future” climate conditions.

Irrigation strategy	ETc_eff 2000	ETc_eff 2050		ETc_eff 2050 late_var	
	[mm/season]	[mm/season]	(variation vs 2000)	[mm/season]	(variation vs 2000)
full	678.2	649.7	-4.2%	699.6	3.2%
mild1	655.7	627.0	-4.4%	674.4	2.9%
mild2	599.2	572.9	-4.4%	614.2	2.5%
medium	578.5	547.4	-5.4%	585.0	1.1%
severe1	501.4	473.9	-5.5%	507.9	1.3%
severe2	388.3	362.3	-6.7%	384.9	-0.9%
rainfed	194.5	172.7	-11.2%	180.8	-7.0%

Tab. 163 – Effect of irrigation strategies and variety selection on the net irrigation requirements of maize in Sardinia Region (Italy) under “present” and “future” climate conditions.

Irrigation strategy	NIR 2000	NIR 2050		NIR 2050 late_var	
	[mm/season]	[mm/season]	(variation vs 2000)	[mm/season]	(variation vs 2000)
full	557.9	551.3	-1.2%	582.5	4.4%
mild1	512.3	500.9	-2.2%	539.4	5.3%
mild2	446.3	441.0	-1.2%	466.0	4.4%
medium	423.1	423.4	0.1%	448.0	5.9%
severe1	333.0	325.6	-2.2%	350.6	5.3%
severe2	211.6	211.7	0.1%	224.0	5.9%
rainfed	0.0	0.0	0.0%	0.0	0.0%

- by plotting together the values of seasonal ETc_{eff} and NIR (obtained under different irrigation strategies and variety) for different climate scenarios, there is a clear prediction of their reduction (respectively of about -5.0% and -1.5%, on average) while, by considering a late maturing variety they are projected to increase (respectively of about +1.9% and +4.9%) (fig. 133);
- the cumulative curves of ETc_{max} in 2050 (versus 2000) show always a clear shifting towards higher values, thus representing the relative increase in the daily crop water requirements, although with a decrease in the cumulative final value (depending on the anticipated ending of the cycle) (fig. 135).

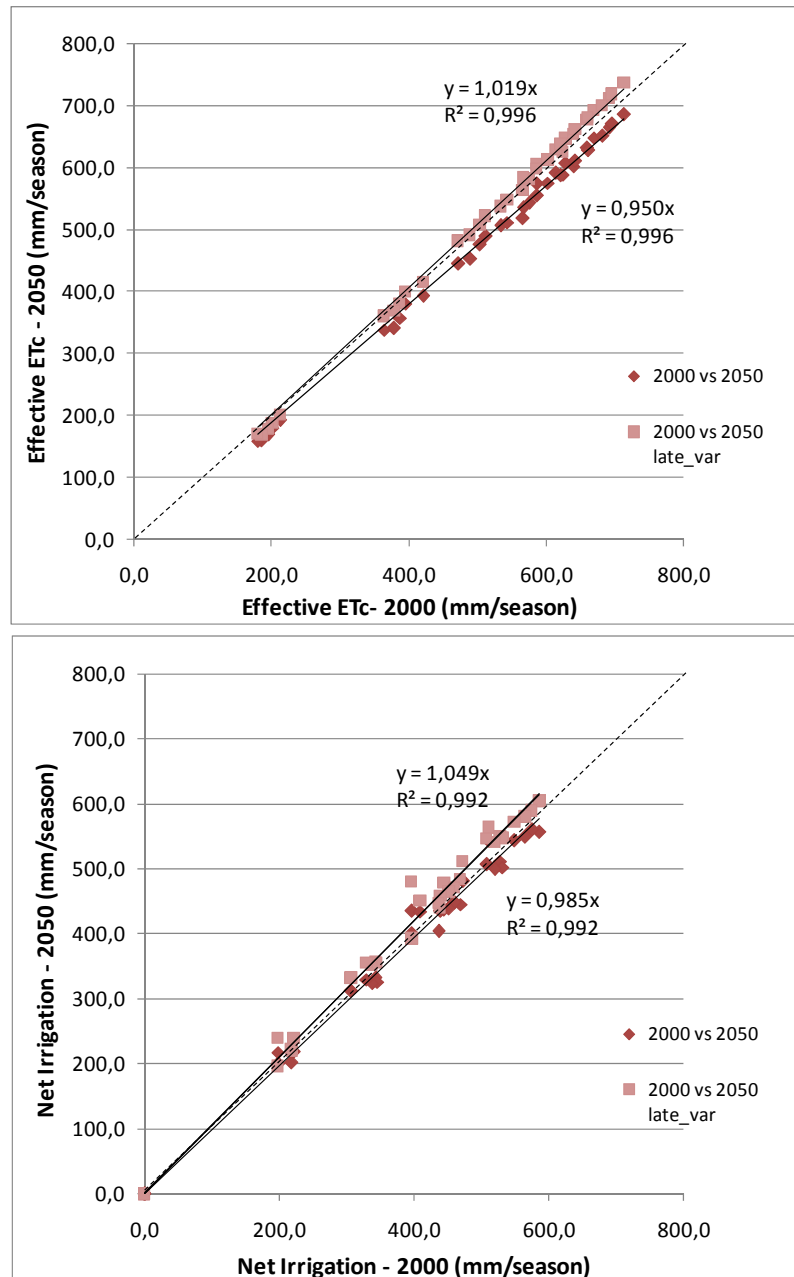


Fig. 133 – Scatter-plot of seasonal crop evapotranspiration and net irrigation requirements of as affected by different variety selection for maize in Sardinia Region (Italy) under “present” and “future” climate conditions.

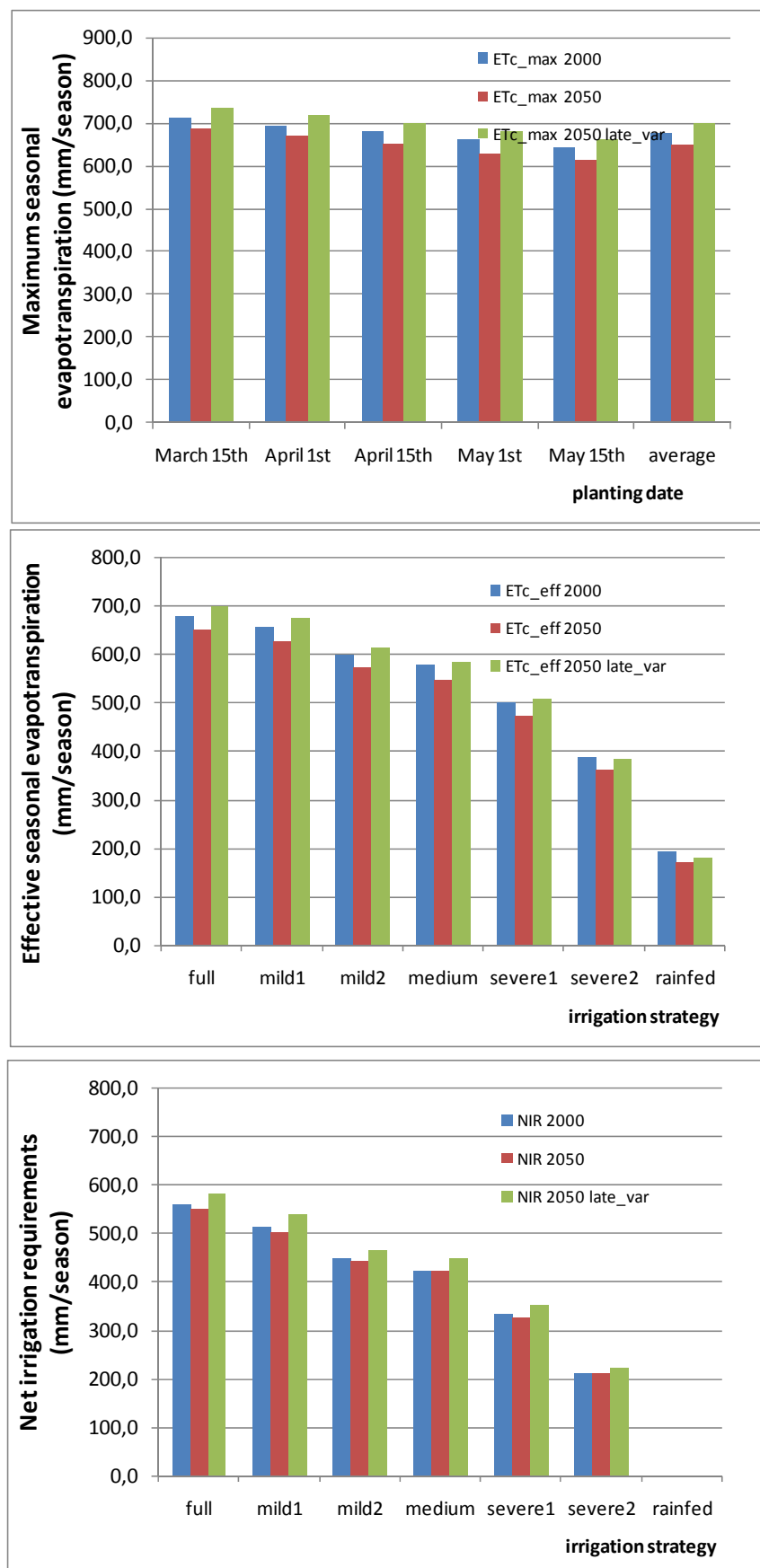


Fig. 134 – Effect of planting date, irrigation strategies and variety selection on maximum and effective crop evapotranspiration and net irrigation requirements of maize in Sardinia Region (Italy) under “present” and “future” climate conditions.

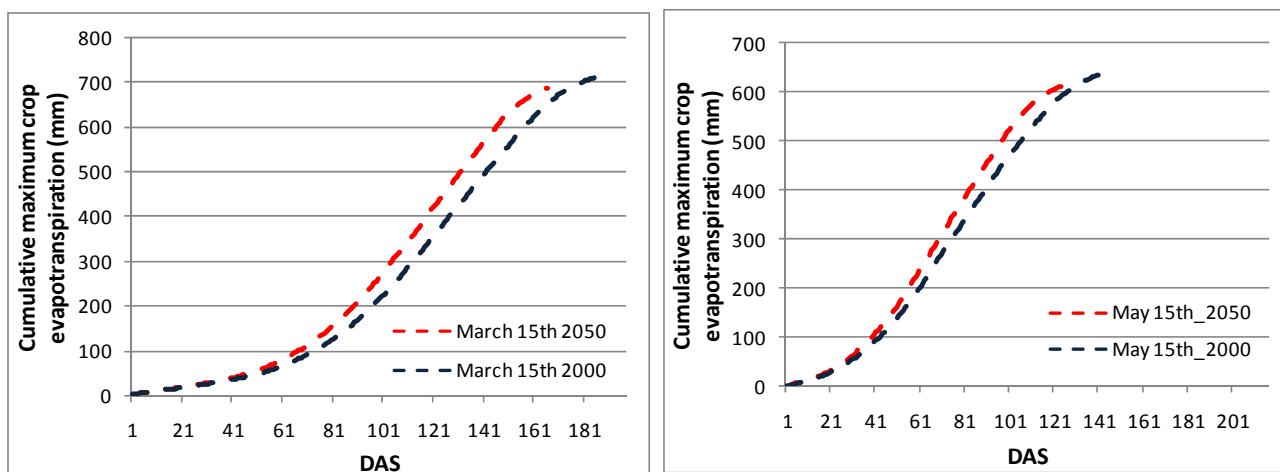


Fig. 134 – Cumulative curves of maximum crop evapotranspiration as affected by different planting date for maize in Sardinia Region (Italy) under “present” and “future” climate conditions.

7.4.3. Yield response to water

The impact of climate change on potential yield, also considering the relative effect of selected adaptation strategies (planting dates, variety selection and deficit irrigation strategies), is summarized in the following tables and graphs. In brief, the following observations are reported:

- yield is projected to reduce under “future” scenario (2050) with respect to current conditions (2000), on average from 10.2 to 9.7 t ha⁻¹ (about -4.2%), depending on irrigation strategies (tab. 164 and fig.135) and planting dates (tab.165 and fig. 135), as a consequence of the expected shortening of the crop growing cycle;
- on the contrary, if the expected fertilizing effect due to an increase in atmospheric CO₂ concentration will occur, yield (2050 wp_adj) is projected to increase in quite all conditions (with an average of 11.7 t ha⁻¹, +15.0%), and thus to overcome the effect of the shortening of the crop cycle (fig. 135 and tab.164-165);
- on the other side, if a late maturing variety (2050 late_var) is selected, yield is projected to slightly increase (with an average of 10.5 t ha⁻¹, +3.2%), depending on irrigation strategy and planting dates (fig.135 and tab.164-165);
- there is a clear reduction in potential yield under increasing water stress conditions (fig.135), and under “severe” water stress (thus only supported by supplemental irrigations) values of 2-4 t ha⁻¹ are predicted;
- in the case of rainfed conditions, no yield is expected in all planting conditions;
- yield is observed always to increase (in absolute terms) for earlier planting dates with respect to later ones (fig.135), because of the corresponding increase in total maximum crop evapotranspiration.

Tab. 164 – Effect of irrigation strategies, variety selection and atmospheric CO₂ increase on the potential yield of maize in Sardinia Region (Italy) under “present” and “future” climate conditions.

Irrigation strategy	Yield 2000 (*)	Yield 2050 (*)		Yield 2050 wp_adj (**)		Yield 2050 late_var (*)	
	(t/ha)	(t/ha)	(variation vs 2000)	(t/ha)	(variation vs 2000)	(t/ha)	(variation vs 2000)
full	10.2	9.7	-4.2%	11.7	15.0%	10.5	3.2%
mild1	9.5	9.0	-4.6%	10.8	14.4%	9.7	2.3%
mild2	7.1	6.9	-4.0%	8.2	15.2%	7.3	2.5%
medium	7.2	6.8	-6.3%	8.1	12.4%	7.3	0.3%
severe1	4.5	4.2	-7.4%	5.0	11.2%	4.5	-0.1%
severe2	2.2	2.0	-8.8%	2.4	9.4%	2.2	-1.9%
rainfed	0.0	0.0		0.0		0.0	
(*) assuming wp (2000) = 1.5 (kg/m³)							
(**) assuming wp (2050)= wp(2000)*1.2= 1.8 (kg/m³)							

Tab.165 – Effect of planting date, variety selection and atmospheric CO₂ increase on the potential yield of maize in Sardinia Region (Italy) under “present” and “future” climate conditions.

Irrigation strategy	Yield 2000 (*)	Yield 2050 (*)		Yield 2050 wp_adj (**)		Yield 2050 late_var (*)	
	(t/ha)	(t/ha)	(variation vs 2000)	(t/ha)	(variation vs 2000)	(t/ha)	(variation vs 2000)
March 15th	10.7	10.3	-3.7%	12.4	15.5%	11.0	3.3%
April 1st	10.4	10.1	-3.5%	12.1	15.8%	10.8	3.4%
April 15th	10.2	9.8	-4.3%	11.7	14.8%	10.5	2.9%
May 1st	9.9	9.4	-4.8%	11.3	14.3%	10.2	3.2%
May 15th	9.6	9.2	-4.7%	11.0	14.3%	9.9	3.1%
average	10.2	9.7	-4.2%	11.7	15.0%	10.5	3.2%
(*) assuming wp (2000) = 1.5 (kg/m³)							
(**) assuming wp (2050)= wp(2000)*1.2= 1.8 (kg/m³)							

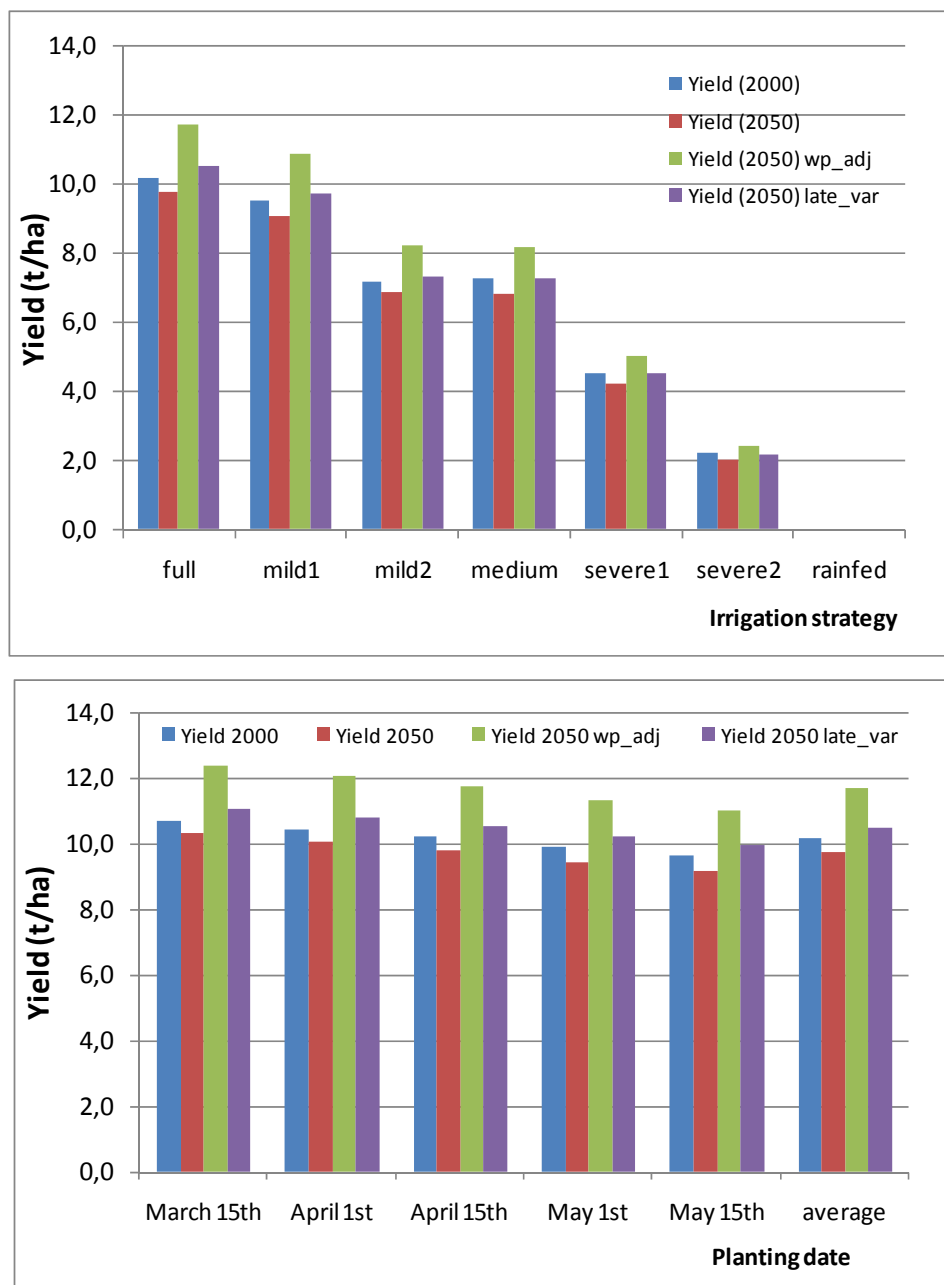


Fig. 135 – Effect of planting date, irrigation strategies, variety selection and atmospheric CO₂ increase on potential yield of maize in Sardinia Region (Italy) under “present” and “future” climate conditions.

7.5. Olive

7.5.1. Cycle length and crop coefficient curves

The effect of temperature increase (and relative GDD accumulation) on current and projected crop cycle of olive has not been evaluated, because of the lack of sufficient information and data to model the relative length of the stages. Thus, a fixed length of the stages and of total growing period has been considered (270 days), as suggested by FAO (2012).

The crop coefficient curves have been modelled by computing the average monthly K_c values according to Orgaz et al. (2006) and FAO (2012) under the different conditions of selected climate scenarios, as affected by the changing of monthly ET_o and rainfall pattern and especially of their relative effect on the evaporative K_c components (from soil and canopy). In table 166, a comparison of the main K_c components is reported, showing the relative reduction of the canopy direct evaporative component (K_{pd}) and of the soil evaporation component ($K_{s,e}$) during the autumn to winter months, due to the projected relative decrease in rainfall pattern and increase in reference evapotranspiration.

In the figure 136, the monthly trends of crop coefficients under different climate scenarios are reported, as computed according to Orgaz et. (2006) for a “new” and an “old” type of olive crop plantation, and in comparison to the fixed K_c coefficient suggested by FAO (2012) for an arid environment; the following observations are reported:

- there is a clear effect of the type of plantation on K_c values, being higher for “new” types of cropping systems under all climate scenarios;
- as yet mentioned, the K_c values for autumn-winter months progressively reduce because of the reduction in projected ET_o and rainfall patterns;
- only slight variations are observed during the spring-summer months, where the K_{pd} and $K_{s,e}$ components reduce close to zero and no variations are observed between scenarios.

Tab. 166 - Comparison of monthly K_c values and main components for olive in Sardinia Region (Italy) under “present”, “future” and “extreme weather” climate conditions.

Month	Kc			Kc.tr	Kpd			Ks.e		
	2000	2050	2050+1	Avg	2000	2050	2050+1	2000	2050	2050+1
1	1.21	1.17	0.98	0.26	0.24	0.23	0.15	0.66	0.63	0.51
2	0.75	0.88	0.76	0.27	0.07	0.12	0.08	0.34	0.43	0.35
3	0.87	0.80	0.70	0.29	0.12	0.09	0.06	0.40	0.35	0.29
4	0.68	0.67	0.62	0.33	0.05	0.05	0.03	0.24	0.24	0.19
5	0.65	0.54	0.52	0.38	0.03	0.01	0.00	0.17	0.09	0.08
6	0.60	0.58	0.57	0.46	0.01	0.01	0.00	0.07	0.06	0.04
7	0.58	0.57	0.55	0.46	0.01	0.01	0.00	0.05	0.04	0.03
8	0.56	0.60	0.58	0.44	0.00	0.02	0.01	0.06	0.09	0.07
9	0.71	0.68	0.63	0.40	0.05	0.04	0.03	0.20	0.18	0.14
10	1.00	0.96	0.86	0.44	0.12	0.10	0.07	0.38	0.35	0.29
11	1.10	1.04	0.91	0.40	0.15	0.13	0.09	0.49	0.45	0.36
12	1.25	1.08	0.91	0.26	0.26	0.19	0.13	0.68	0.58	0.47

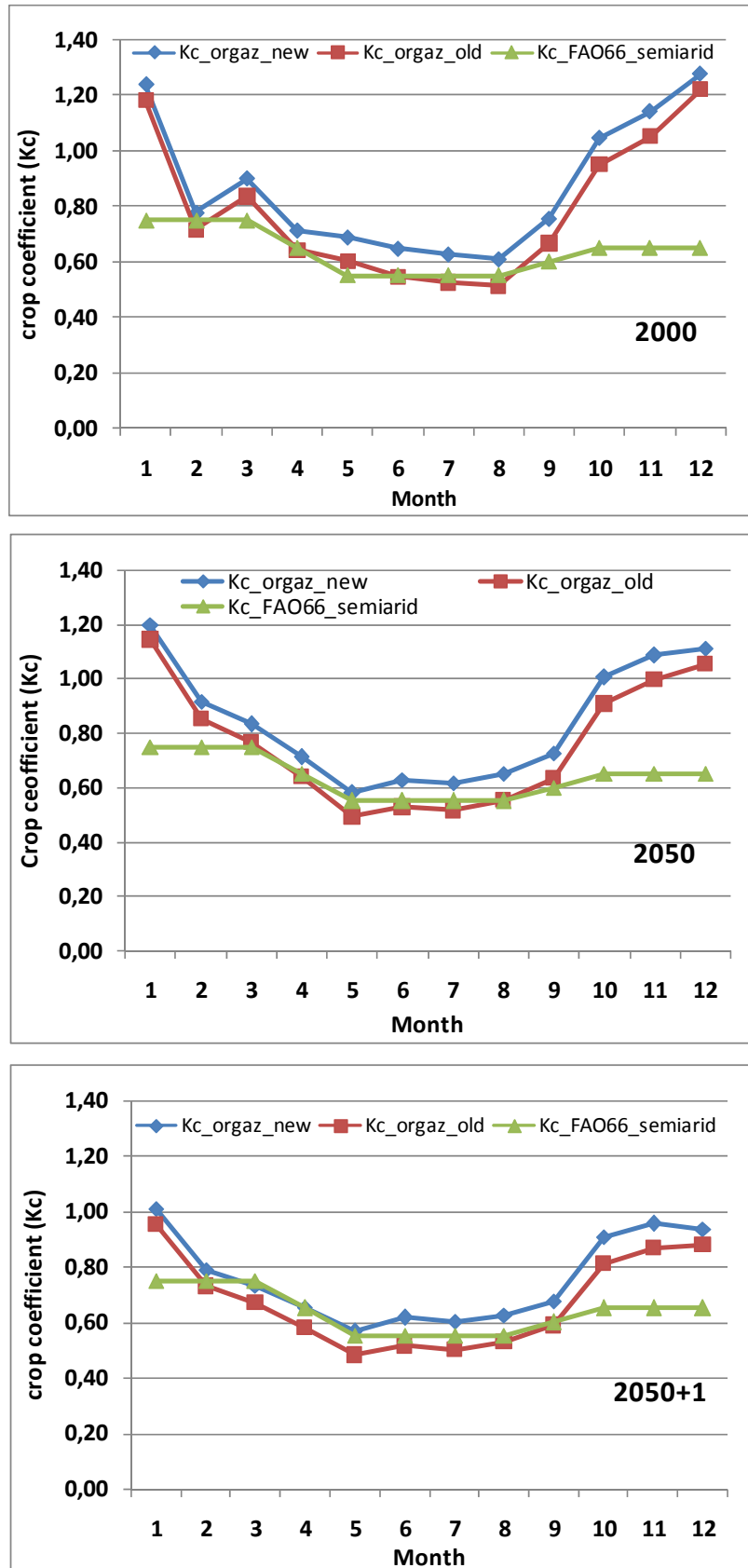


Fig. 136 - Trends of monthly Kc coefficients for olive in Sardinia Region (Italy) under “present”, “future” and “extreme weather” climate conditions.

7.5.2. Crop evapotranspiration and irrigation requirements

The impact of climate change on maximum and effective crop evapotranspiration as well as on net irrigation requirements, also considering the relative effect of selected adaptation strategies (deficit irrigation strategies), is summarized in the following tables and graphs. In brief, the following observations are reported:

- maximum seasonal crop evapotranspiration is projected to increase for all crop models under “future” (2050) scenario, because of the fixed duration of cycle length and probably as a consequence of the expected increase in daily ET_o , on average of about +3.5% with respect to current conditions (2000) (fig. 137 and tab.167);
- if “extreme weather” conditions (2050+1) are considered, the projected maximum evapotranspiration variation is slightly lower (on average of about +2.5%), but with some important differences between the models (fig. 137 and tab.167);
- the higher values of maximum seasonal crop evapotranspiration are observed for the “new” cropping type, under all climate scenarios (fig.137 and tab.167);
- the relative effect of the projected increase and/or decrease of rainfall patterns (during the period March-November), seems to be relatively important for the crop water balance, especially under “extreme weather” scenario (about -100 mm), and with respect to the impact for the severe stressed to rainfed conditions (tab.168);
- ETc_{eff} and NIR are both highly dependent on the irrigation strategy, progressively reducing going from full irrigation to rainfed conditions, under all climate scenarios (fig.137);
- ETc_{eff} is projected to increase under both 2050 (on average +2.7%) and 2050+1 (+1.2%) scenarios, for full to mild irrigation strategies, but it is projected to decrease from medium to severe stressed and rainfed conditions (on average -2.3% and -11.1%), in which a reduction is projected because of the reduction of the rainfall patterns, especially under “extreme weather” scenario (tab.169);
- as a consequence, NIR is projected to increase for all irrigation strategies under both 2050 (on average +12.8%) and 2050+1 (+26.6%) scenarios (tab.170).

Tab. 167 – Maximum crop evapotranspiration as estimated by different Kc models for olive in Sardinia Region (Italy) under “present”, “future” and “extreme weather” climate conditions.

Crop model	ETc_max 2000	ETc_max 2050		ETc_max 2050 +1	
	[mm/season]	[mm/season]	(variation vs 2000)	[mm/season]	(variation vs 2000)
Old_Orgaz_270	665.7	678.2	1.9%	655.3	-1.6%
New_Orgaz_270	760.3	779.0	2.5%	759.4	-0.1%
FAO66_270	611.6	651.2	6.5%	673.2	10.1%
average	679.2	702.8	3.5%	696.0	2.5%

Tab. 168 – Effective rainfall pattern during crop cycle of olive in Sardinia Region (Italy) under “present”, “future” and “extreme weather” climate conditions.

Crop model	Rain_eff 2000	Rain_eff 2050		Rain_eff 2050 +1	
	[mm/season]	[mm/season]	(variation vs 2000)	[mm/season]	(variation vs 2000)
Old_Orgaz_270	306.3	287.3	-6.2%	201.1	-34.3%
New_Orgaz_270	306.3	287.3	-6.2%	201.1	-34.3%
FAO66_270	306.3	287.3	-6.2%	201.1	-34.3%
average	306.3	287.3	-6.2%	201.1	-34.3%

Tab. 169 – Effect of irrigation strategies on the effective crop evapotranspiration of olive in Sardinia Region (Italy) under “present”, “future” and “extreme weather” climate conditions.

Irrigation strategy	ETc_eff 2000	ETc_eff 2050		ETc_eff 2050+1	
	[mm/season]	[mm/season]	(variation vs 2000)	[mm/season]	(variation vs 2000)
full	679.2	702.8	3.5%	696.0	2.5%
mild1	664.3	682.7	2.8%	678.5	2.2%
mild2	641.7	655.2	2.1%	635.4	-1.0%
medium	598.7	612.5	2.3%	566.3	-5.4%
severe1	571.8	568.9	-0.5%	547.8	-4.2%
severe2	486.7	482.2	-0.9%	428.4	-12.0%
rainfed	372.2	351.4	-5.6%	287.1	-22.9%

Tab. 170 – Effect of irrigation strategies on the net irrigation requirements of olive in Sardinia Region (Italy) under “present”, “future” and “extreme weather” climate conditions.

Irrigation strategy	NIR 2000	NIR 2050		NIR 2050 +1	
	[mm/season]	[mm/season]	(variation vs 2000)	[mm/season]	(variation vs 2000)
full	350.5	404.4	15.4%	454.4	29.7%
mild1	333.4	363.3	8.9%	422.3	26.7%
mild2	280.4	323.5	15.4%	363.5	29.7%
medium	230.2	262.4	14.0%	283.9	23.3%
severe1	216.7	236.1	8.9%	274.5	26.7%
severe2	115.1	131.2	14.0%	141.9	23.3%
rainfed	0.0	0.0	0.0%	0.0	0.0%

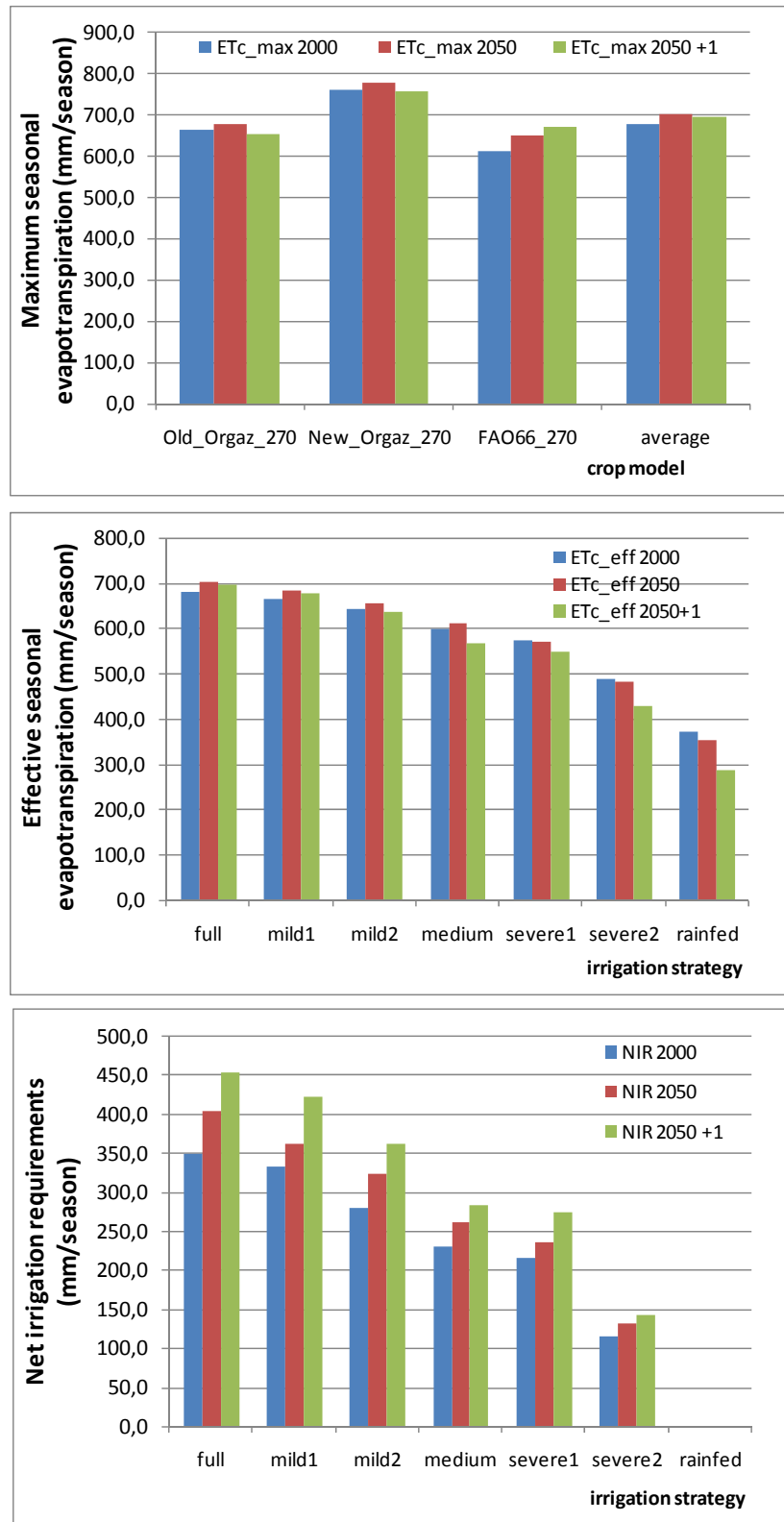


Fig. 137 – Effect of Kc model and irrigation strategies on maximum and effective crop evapotranspiration and net irrigation requirements of olive in Sardinia Region (Italy) under “present”, “future” and “extreme weather” climate conditions.

7.5.3. Yield response to water

The impact of climate change on potential yield, considering the relative effect of selected adaptation strategies (deficit irrigation strategies), as estimated by the two different yield response models of Rao *et al.* (1988) and Moriana *et al.* (2003) (presented in chapter 2.1.3) are summarized in the following tables and graphs.

According to the results of the first model (Rao *et al.*, 1988) (tab. 171-172 and fig.138):

- on average, maximum yield is projected to increase under future scenarios, going from 13.6 t ha⁻¹ (2000) respectively to 14.1 t ha⁻¹ (2050) and 13.9 t ha⁻¹ (2050+1);
- actual yield is projected to increase and/or decrease under “future” (2050) and “extreme weather” (2050+1) scenarios with respect to current conditions (2000), depending on irrigation strategies and Kc model considered, as a consequence of the expected increase of *ETc*;
- an important reduction in actual yield is predicted for severe stressed and rainfed conditions, on average from -2.5% for 2050 to -16.7 for 2050+1;
- under “severe” water stress (thus only supported by supplemental irrigations) values of 4-7 t ha⁻¹ are still predicted; in the case of rainfed conditions, very low yield (around 1.5-2 t ha⁻¹) is predicted.

According to the results of the alternative model (Moriana *et al.*, 2003) (tab. 173-174 and fig.139):

- on average, maximum yield is projected to increase under future scenarios, going from 9.8 t ha⁻¹ (2000) to 10.1 t ha⁻¹ (2050 and 2050+1);
- actual yield is projected to increase only with mild to medium stressed conditions under both “future” and “extreme weather” scenarios; on the contrary, under severe stressed conditions, yield reductions respectively from -1.6% to -20% are predicted;
- a linear decrease in potential yield is predicted going from full irrigated to severe stress (only supported by supplemental irrigations) where values of 4-7 t ha⁻¹ are still predicted; in the case of rainfed conditions, no yield is predicted under “extreme weather” conditions.

Tab. 171 – Effect of irrigation strategies on the potential yield of olive in Sardinia Region (Italy) under “present”, “future” and “extreme weather” climate conditions.

Irrigation strategy	Yield 2000 (*)	Yield 2050 (*)		Yield 2050 +1 (*)	
	(t/ha)	(t/ha)	(variation vs 2000)	(t/ha)	(variation vs 2000)
full	13.6	14.1	3.5%	13.9	2.5%
mild1	13.1	13.4	2.2%	13.4	1.8%
mild2	11.9	11.9	0.3%	11.4	-4.4%
medium	11.0	11.1	1.7%	9.9	-9.4%
severe1	9.3	9.0	-2.9%	8.5	-8.1%
severe2	6.7	6.5	-1.9%	5.6	-16.3%
rainfed	2.7	2.7	-2.7%	2.0	-25.7%
(*) assuming wp (2000) =		2 (kg/m3)			

Tab. 172 – Effect of different Kc models on the potential yield of olive in Sardinia Region (Italy) under “present” and “future” climate conditions.

Crop model	Yield 2000 (*)	Yield 2050 (*)		Yield 2050 +1 (*)	
	(t/ha)	(t/ha)	(variation vs 2000)	(t/ha)	(variation vs 2000)
Old_Orgaz_270	13.3	13.6	1.9%	13.1	-1.6%
New_Orgaz_270	15.2	15.6	2.5%	15.2	-0.1%
FAO66_270	12.2	13.0	6.5%	13.5	10.1%
average	13.6	14.1	3.5%	13.9	2.5%
(*) assuming wp (2000) =		2 (kg/m3)			

Tab. 173 – Effect of irrigation strategies on the potential yield of olive in Sardinia Region (Italy) (as modelled according to Moriana *et al.* 2003) under “present”, “future” and “extreme weather” climate conditions.

Irrigation strategy	Yield 2000 (**)	Yield 2050 (**)		Yield 2050 +1 (**)	
	(t/ha)	(t/ha)	(variation vs 2000)	(t/ha)	(variation vs 2000)
full	9.8	10.1	3.5%	10.1	2.5%
mild1	9.6	9.9	3.1%	9.8	2.4%
mild2	9.2	9.4	2.6%	9.1	-1.3%
medium	8.3	8.6	3.4%	7.6	-8.6%
severe1	7.7	7.7	-0.9%	7.2	-7.4%
severe2	5.5	5.4	-2.4%	3.7	-32.7%
rainfed	1.8	1.0	-44.6%	0.0	-100.0%
(**) according to the model proposed by Moriana <i>et al.</i> (2003)					

Tab. 174 – Effect of different Kc models on the potential yield of olive in Sardinia Region (Italy) (as modelled according to Moriana *et al.* 2003) under “present” and “future” climate conditions.

Crop model	Yield 2000 (**)	Yield 2050 (**)		Yield 2050 (**)	
	(t/ha)	(t/ha)	(variation vs 2000)	(t/ha)	(variation vs 2000)
Old_Orgaz_270	9.6	9.8	2.1%	9.4	-1.8%
New_Orgaz_270	10.8	11.0	1.6%	10.8	-0.1%
FAO66_270	8.6	9.3	8.6%	9.7	12.9%
average	9.8	10.1	3.5%	10.1	2.5%
(**) according to the model proposed by Moriana <i>et al.</i> (2003)					

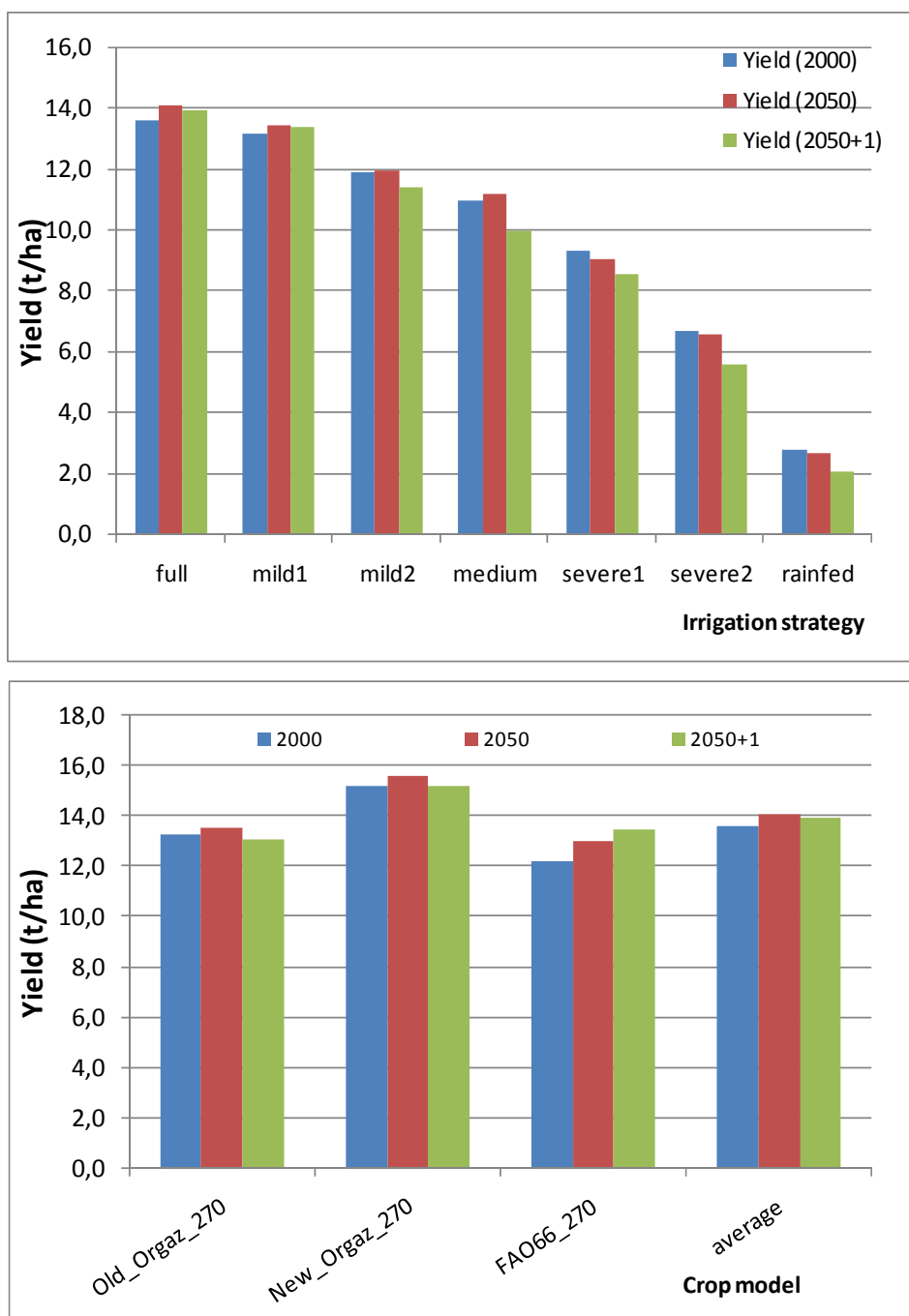


Fig. 138 – Effect of irrigation strategies and Kc model on potential yield of olive in Sardinia Region (Italy) under “present” and “future” climate conditions.

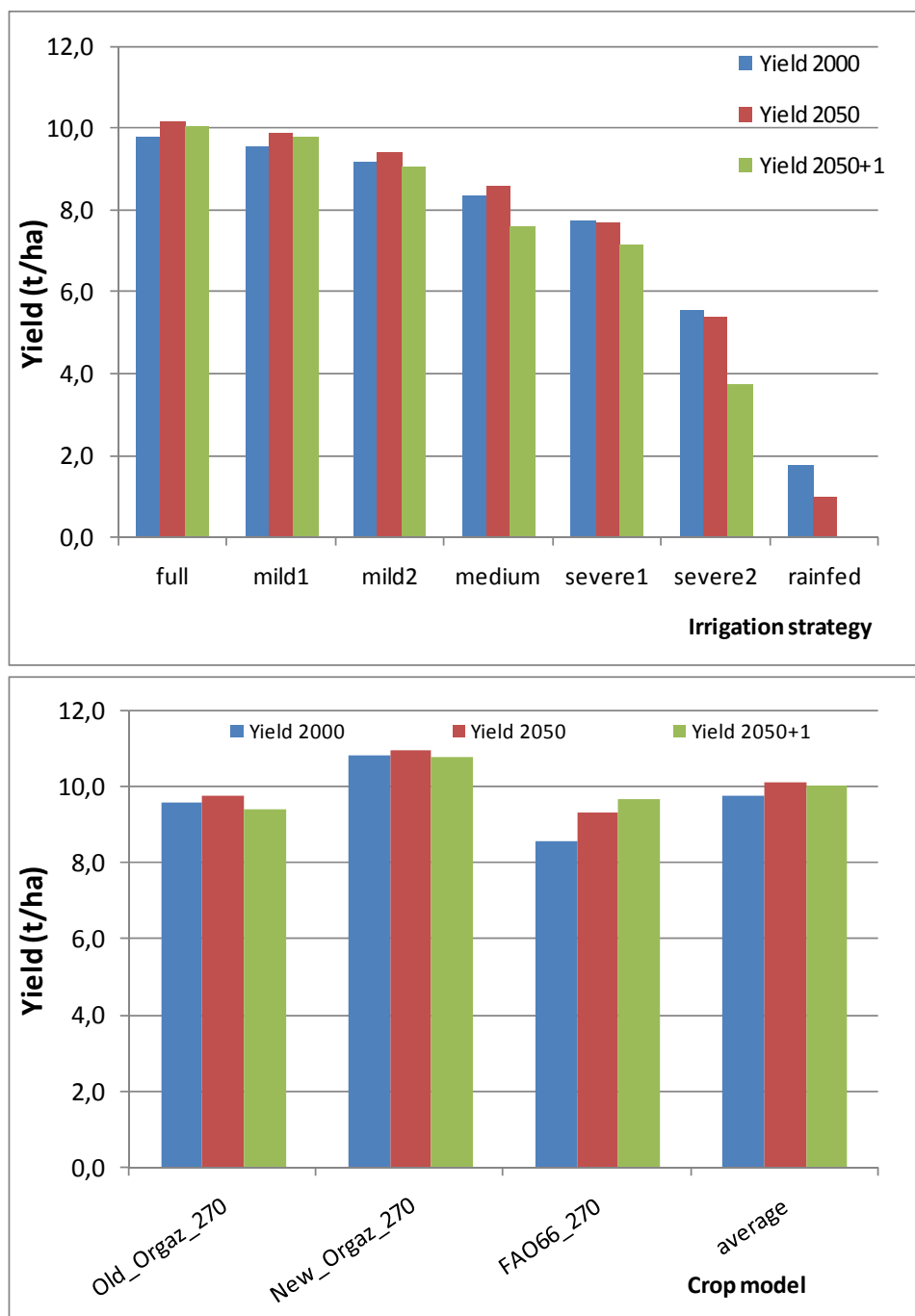


Fig. 139 – Effect of irrigation strategies and Kc model on potential yield of olive in Sardinia Region (Italy) (as modelled according to Moriana *et al.* 2003) under “present” and “future” climate conditions.

8. Conclusions

According to the results of this work, the following synthetic observations and conclusions can be reported:

- a) The main effect of temperature rise under future climate scenario (2050) will be the **shortening of the growing cycle** for all annual crops examined, in all case study areas. The relative percentage of reduction in cropping cycle duration depends on the average predicted temperature variation and its effect on GDD accumulation.
- b) In most cases, the reduction in cycle length and the shifting of the K_c curve, will determine a **reduction in the maximum seasonal crop evapotranspiration**, and thus of the total annual crop water requirements.
- c) As a consequence, also the seasonal **effective crop evapotranspiration and net irrigation requirements are normally projected to decrease** in 2050, but the relative percentages of reduction depend mostly on the specific case study area and irrigation strategy selected. On the other side, crop evapotranspiration measured on the shorter time scale (daily, weekly or monthly) is however predicted to increase, thus determining a higher rate of crop water requirements and irrigation (higher frequency or amount of irrigation needed during the scheduling, although the final total amount will be less because of the shorter cropping season).
- d) The present analysis highlights that the main effect of the shortening of the growing period will result in **lower crop transpiration** and thus in a shorter time and rate of biomass accumulation, and thus in the **reduction of crop yield**. These changes in yields will be not homogeneous and will depend on crop phenology (e.g. summer and winter crops), crop type (C3 and C4 plants) or environmental conditions (water availability). This is in agreement with several other CC simulation studies aimed at assessing the effect of changes in mean climate conditions (i.e. Bindi et al., 1996; Singh et al., 1998; Giannakopoulos et al., 2009).
- 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 fertilizing effect due to an **increase in atmospheric CO_2 concentration** will occur, **yield (2050 wp_adj) is projected to increase in quite all conditions**, and thus to overcome the effect of the shortening of the crop cycle.
- f) Nevertheless (and apart from the CO_2 fertilizing effect), reductions in the yield of determinate crops due to shorter crop durations could be countered by **changing to a variety which has a longer crop duration** in future climates, and with different sensitivities to temperature and/or photoperiod. Anyway, this adaptation strategy will determine quite always an **increase in seasonal maximum crop evapotranspiration and net irrigation requirements**.
- g) Then, an effective combination of **planting date** and **deficit irrigation strategy** could be very helpful in ensuring the conservation of appropriate yield without excessive increase in crop water requirements. In some cases, also under severe water stress conditions, only supporting crops with supplemental irrigation, still good levels of yield have been predicted.

- h) In the case of “**extreme weather**” conditions, a further important reduction of the total growing cycle is predicted for quite all planting dates with respect to 2000 and 2050 scenario, because of the faster accumulation of the required GDD sum; as a consequence, the reduction in yield will be more important. If a late maturing variety is considered, the total crop cycle length (2050+1 late_var) is normally only partly recovered with respect to present (2000) scenario. Additionally, an **increase** of both effective **crop evapotranspiration** and (more significantly) of net **irrigation requirements** has been predicted.

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