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Modelling for water supply of irrigated cropping systems on climate change

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Abstract

The vulnerability of Mediterranean environment due to climatic changes makes necessary to define the effects of the increase of CO_2 atmospheric concentration and the consequent alterations of temperature and precipitation variations upon the processes which regulate the plants water supply. The traditional research can not meet the needs of this information because of the difficulty of carrying out the experiments. Therefore, it is necessary to use models based upon mathematical representation of the processes and interactions between climatic scenarios, plant and soil, with which to simulate different agronomic situations. The integration of global circulation models with water balance models is a valid tool for studying the influence of climatic changes on water supply. This study took into account the influence of climatic changes on water supply of poly-annual (artichoke and asparagus) and annual (potato and broccoli) crops with the CRITERIA simulation model of water balance. The simulations were performed with two future climate scenarios (A2 and B1). The results of the simulations highlight how the A2 scenario gives a greater influence on cycle length of crops which develop in summer time determining a reduction of crop cycle from 15-20% compared to the observed data, and so, as a consequence in the future, the crops with a summer crop cycle will be subjected to reductions of water supply up to 25%.

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Introduction

The results of the international scientific research in the climatology field are showing more convincing proves that we are going through a period of global climatic change.

The Earth's climate is adapting to the increase of greenhouse gas emission levels occurring in the last 150 years, commonly known as the major reason of variation together with the overlapping to natural climatic changes. In the last decades, observations of trends in temperature confirmed the tendency towards change expected by mathematical models, and not all attributable to natural variation. In the production sectors, agriculture represents beyond doubt one of those most sensitive to the current changes being strongly dependent on climate and meteorological trends (Maracchi *et al*., 2005). By an evaluation of annual trends of precipitation and water losses (evapotranspiration - ET_{ref}) in the Mediterranean environment it can be inferred that it is not possible to ignore irrigation to cultivate species which complete fully or partially their growth cycle during spring and summer time. Moreover, irrigation seasons are longer and longer and also autumn and winter species may require irrigation for obtaining convenient yields (Campi *et al*., 2005).

In addition, recent studies on the extent of global warming have shown how the increase in temperature is not uniform. In fact, there are areas where the temperature is increased whereas there are others with decreased temperature. In particular, the main international studies achieved can foresee more increased temperatures in the Mediterranean Basin. The tendency of precipitation forecast is rather uncertain: on the whole, the main probabilities indicate a reduction of precipitation in the Mediterranean area (Alcamo *et al*., 2007). An important decrease in effective rainfall with a sensitive increase in the mean temperature might favourite the process of desertification in southern Italy (Borrelli *et al*., 2002). The vulnerability in the Mediterranean area to climatic changes makes necessary to define the effects of the alterations of temperatures and precipitation variations on the processes which regulate the crop water requirements to planning crop rotation, irrigation scheduling, etc. The traditional research can not meet completely the need of this information because it is extremely difficult to carry out these experiments. In fact, the traditional experiments are carried out in particular conditions of time and space and thus the results are specific for a well-defined place and season (Lovelli *et al*., 2010). Therefore, it is necessary to access models based on a mathematical representation of the processes and interactions between climatic scenarios, plant and soil, with which to simulate the various agronomic situations. Although there are many difficulties for the calibration and validation of the models, they can be overcome if it is achieved a high level of confidence with the model that will produce dependable forecasts. Among the different models to simulate this processes, the CRITERIA (Marletto and Zinoni, 1996) model, developed at ARPASIM, simulates crop water supply at a regional scale. CRITERIA, provided by daily data of precipitation and temperature, estimates the evapotranspiration and calculates the daily flow of superficial runoff, hypodermic runoff and drainage. The water balance takes into account the phenomena of precipitation, irrigation, capillary rise, runoff, evapotranspiration, percolation, redistribution and deep drainage. Some of these variables, such as the precipitation, are easily to be measured; others are estimated through algorithms based on meteorological data and characteristics of soil and crops. The water balance is calculated on a daily basis. In this study CRITERIA model was utilized to predict the influence of climatic changes on water supply of poly-annual (artichoke and asparagus) and annual (summer-spring potato and autumnal broccoli) crops. The model was calibrated and validated with data obtained by a trial carried out on field, and the simulations were related to two future scenarios A2 and B1 (IPCC, 2007).

Materials and methods

The trials were carried out in southern Italy on artichoke, asparagus, potato and broccoli crops. In addition, the irrigation treatments were differentiated to obtain agronomic data set to calibrate the CRITERIA model. The research for the artichoke (cv *Violetto di Provenza*) was carried out on farm in Foggia (41°22' NL, 15°35' EL, 80 m asl) characterized by a semi-arid Mediterranean climate (rainfall=550 mm, and average temperature=16°C). The soil was characterized by 45% clay and 35% silt and the water contents (measured with Richards chambers) at the field capacity and at the wilting point were 37 and 20 kg kg^{-1}, respectively. The artichoke was transplanted in September 2007, while the irrigation treatments started in July 2008 and 2009, by forcing the *sleeping* crop through abundant irrigations (70 and 30 mm, respectively on 1st July 2008 and on 15th July 2009). The trials for asparagus (cv *Grande*), broccoli (cv *Medway*) and potato (cv *Arinda*) were carried out at the experimental farm of the Agricultural Research Council-Research Unit for Cropping Systems in Dry Environments (CRA-SCA), in Rutigliano (BA) (40°59' NL, 17°59' EL, 147 m asl). The location is characterized by a Maritime-Mediterranean climate. The average annual rainfall is 590 mm, concentrated mostly during the autumn, while quite scarce during spring and summer (data recorded from 1980 until 2010 at the Rutigliano agro-meteorological station). The rainfall amount is insufficient to meet the evapotranspiration demand of the atmosphere. The annual ET_{ref} is equal to 1150 mm, therefore the annual water deficit is 560 mm (Campi *et al*., 2005). The soil was characterized by 40% clay and 45% silt and the water contents (measured with Richards chambers) at the field capacity and at the wilting point were 30 and 18 kg kg^{-1}, respectively. These textural and hydrological characteristics do not change significantly with the horizontal and vertical dimensions. The soil profile is not deep (<1 m) and has a moderate total available water (TAW=133 mm m^{-1}). Dates of sowing or transplanting of each crop and the lengths of the crop cycles are reported in Table 1. The irrigation volumes were estimated by the FAO 56-model and the experimental design, for each crop, was made up of two irrigation regimes: i) 100ET: well-irrigated control restoring 100% ET_c; ii) 50ET: sub-optimal irrigation by reducing irrigation volume by 50% in comparison with the control treatment. The FAO crop coefficients (Allen *et al*., 1998) were adopted (Table 2). A *strip-plot* experimental design was used for each crop, three times replicated. The asparagus and artichoke were irrigated with a micro-flow system (drips) whereas the potato and broccoli were irrigated with an aspersion system (lateral *rainger*). In order to validate the ET estimated by the CRITERIA model, the daily crop evapotranspiration (ET_d) was determined indirectly with the water balance method (Lhomme and Katerji, 1991). The method requires the measurement of the daily variations in soil humidity (ΔW). These measurements were derived by the values of the dielectric constant which were measured hourly by coaxial probes (0.3 m in length). They were installed, before sowing/transplanting, horizontally into the soil at 0.3 m in depth. Probes were linked to a TDR100-Campbell data logger CR1000 (Campbell Scientific, Inc., Logan, UT, USA). These data were used as the input for the Topp equation (Topp and Davis, 1985) which allows for the calculation of the percentage (in volume) of water in the soil. As the Topp equation refers to a generic clay soil, a local calibration was adopted. During a cycle of dehydration of the soil (15 days), the soil humidity values calculated by the Topp equation were correlated to those daily obtained with the reference method (thermo-gravimetric). A linear regression was found for each TDR probe between the humidity values provided by the two methods (Topp equation and thermo-gravimetric). The slope and the intercept of such regressions allowed the local calibration of the TDR-probes.

The daily variation of soil humidity (±ΔW) and rain (R) allowed to come up with the ETd, the only unknown term in the equation:

$$ET_d = \pm\Delta W + R - D \quad (1)$$

The equation for the water balance (1) was simplified to only three terms (Mastrorilli, 1999), since the runoff and capillary rise in the experimental fields (Rutigliano and Foggia) are negligible. In fact, the experimental areas are flat, the soil superficial and sub-soil impedes capillary rise from the deepest layers. Drainage (D) was calculated as equal to the excess of water supply with regards to the capacity of the soil to retain water.

The seasonal water consumption was estimated through the accumulation of ETz-.

The calibration of the CRITERIA model was done taking into account the following inputs measured during the tests:

- Agrometeorological data.
- Leaf Area Index (LAI) trend: it is measured through thermic sums and related values of LAI which are necessary for the initial growth phase (from the transplant to the beginning of growth and from this latter to the maximum development of leaves) and senescence (up to harvesting) to be completed.
- Crop coefficient (Kc): It was taken into account and it was obtained by the ratio between ETd, calculated with the Eq. 1 for optimal irrigation's condition (100ET), and ET_0, calculated with Penman-Monteith model (Table 3).

Table 1. Month of sowing or transplanting of crops and duration years of trials.

Crop	Sowing/transplanting	Years of trials
Artichoke	September 2007	2008-2009
Asparagus	May 2006	2008-2009
Broccoli	September	2008 and 2009
Potato	April	2009 and 2010

Table 2. The basal FAO crops coefficients (K_c) adopted to calculate crop evapotranspiration.

Crop	K_c ini	K_c med	K_c end
Artichoke	0.15	0.95	0.90
Asparagus	0.15	0.9	0.2
Broccoli	0.15	0.95	0.85
Potato	0.15	1.1	0.6

Table 3. Crop coefficient (K_c) and fraction depletion (P) values adopted in the irrigation management.

Crop	K_c	P
Artichoke	1.15	0.45
Asparagus	1.05	0.45
Broccoli	0.80	0.40
Potato	1.15	0.35

- Root depth: a depth of 0.6m was taken into account for all the crops.
- Physical-chemical and hydrological characteristics.
- Irrigation management: an irrigation is scheduled every time the readily water availability is depleted (FC – p TAW), where p is the threshold value indicated by the FAO 56 (Allen *et al*., 1998) (Table 3). The sub-optimal regimes are managed by the stress coefficients (0-0.99) which come from the ratio between the effective and the maximum transpiration. The coefficients of 0.9 and 0.5 were taken into account for the optimal management (100ET) and for the irrigation deficit (50ET), respectively.

For model calibration a data set related to only one year (2009) was used. For simulating water supply in future scenarios, the effect of CO_2 on transpiration flow during calibration was not taken into account because the effect, due to the interaction between temperature and CO_2, is uncertain (Polley *et al*., 2002).

In this area of knowledge, for the trials regarding climatic changes it was observed that the increase in CO_2 atmospheric concentration results in an increase in stomatal resistance, approximately around 22% (Ainsworth *et al*., 2005). As a consequence, there is a reduction of water loss by transpiration. Considering that the transpiration is determined by the vapour pressure gradient between the internal and external part of the leaves, and that this gradient is closely related to the temperature, if this one increases, the transpiration should increase as well. Therefore, a simultaneous action shows up between two effects which drive in opposite directions and can be mutually balanced at leaf's level (Lovelli *et al*., 2010).

For the model validation the ET was considered, for each crop, year and irrigation treatment. The statistical validation followed the methodology proposed by Loague and Green (1991). Relative Root Mean Square Error (RRMSE) was calculated as follows:

$$RRMSE = \sqrt{\frac{\sum_{i=1}^{n}(P_i - O_i)^2}{n}} \cdot \frac{100}{\bar{O}} \qquad (2)$$

where n is the number of observations, P_i is the crop evapotranspiration value predicted by CRITERIA (ET_{crit}), Oi the observed crop evapotranspiration value (ET_s), and $\bar{O}$ the mean of the observed values. RRMSE gives a percentage measurement of the difference between simulated vs observed data. The validation is considered to be excellent when RRMSE is <10%, good if between 10-20%, acceptable if between 20-30, poor >30 (Jamieson *et al*., 1991). The RRMSE test provides a value for the model's prediction error rate by placing emphasis on a high level of errors.

Figure 1 indicates the RRSME and the trend obtained from the comparison between the cumulative daily values of crop evapotranspiration estimated through the CRITERIA model and the values observed independently through the *water balance* for each of the crops and for the two irrigation schedules (100ET and 50ET). In particular, taking into account that the RRMSE test indicates a good level of acceptance of errors from the model (RRMSE varies until 20%), the CRITERIA model can correctly estimate ET in future scenarios. The simulations were performed with A2 and B1, past and future climate scenarios respectively, obtained with statistical downscaling (Pizzigalli *et al*., 2012).

For every thirty years span (1980-2005; 2010-2039; 2040-2069; 2070-2099) and for every crop and irrigation treatment, a water balance was simulated with the CRITERIA model. Afterwards the figures of the crop variable (cycle lenght) and irrigation (crop evapotransipration, seasonal irrigation volumes, irrigation number and crop coefficients) were analyzed for every thirty-year period, in relation to the past (A2) and future (B1) climatic scenarios.

Results

Artichoke

The simulations with future scenarios (Figure 2) show that the crop cycle of the artichoke is reduced by 55 days with the A2 scenario in the 2070-2099 period respect to the present one (1980-2005). The reduction of the crop cycle caused, for the optimal irrigation treatment (100 ET), a decrease of 170 and 133 mm in the crop evapotranspiration and in the seasonal irrigation volume, respectively. Also values of K_c have shown at once a reduction with A2 scenario going from a mean value of 0.98 in the period from 1980-2005 to 0.91 in the thirty-year period from 2070 to 2099 (Table 4). With a regulated deficit irrigation (50ET), a reduction in the cultural evapotranspiration and in the seasonal irrigation volume occurred of 191 and 153 mm, respectively.

The simulated data show how the reduction in irrigation volumes does not provoke water stress to the artichoke crop since the deficit irrigation caused an ET mean reduction of 10% in both the past and future scenarios.

Asparagus

The simulations with future scenarios show that the crop parameters taken into account are changed in both scenarios. In particular, the asparagus crop cycle is reduced in the last thirty years period by 40 days in the A2 scenario and by 30 days in the B2 one (Figure 3). As a consequence, the reduction of crop cycle triggered, a reduction in the ET_c and seasonal irrigation volume. In addition, the effects induced by the A2 scenario have been more evident on Kc, whose mean values have been reduced from 0.74 to 0.65 (Table 5). In the asparagus, as occurred with the artichoke, the reduction in irrigation volume does not produce water stress conditions to the crop, since the deficit irrigation involves an ET mean reduction by 14% in both past and future scenarios (A2 and B1).

Broccoli

The simulations for the broccoli crop showed variations only with A2 scenario. Regarding the other crops, an increase of the ETc that result-

Table 4. Simulations of the irrigation variables with past and future scenarios (A2 and B1) on artichoke.

	Scenario	Present		A2						B1					
	Years	1980-2005		2010-2039		2040-2069		2070-2099		2010-2039		2040-2069		2070-2099	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
100ET	ET_c (mm)	987	23	944	12	883	16	817	12	943	14	960	11	957	12
	Irrigation (mm)	546	74	467	62	405	64	413	54	478	77	488	78	459	76
	Irrigation (n)	26	3	22	3	19	3	19	3	22	4	23	4	21	3
	K_c	0.98	0.01	0.97	0.01	0.94	0.02	0.91	0.02	0.97	0.01	0.97	0.02	0.98	0.02
50ET	ET_c (mm)	879	14	855	16	788	23	688	24	838	32	850	22	863	22
	Irrigation (mm)	380	61	320	41	264	38	227	33	325	41	326	45	311	47
	Irrigation (n)	28	4	24	3	20	4	18	2	24	4	24	4	23	4

ed from the simulations does not show any variations in the length of the crop cycle. This can be explained through the higher temperatures with the A2 scenario during the autumnal period compared to those of B1. The increase of ET is the main cause of the increase of Kc from 0.65 to 0.70 with A2 scenario. The regulated water stress did not show any variations of ETc (Table 6).

Potato

The reduction of potato crop cycle, compared to other crops, is more evident with the B1 scenario (Figure 4). The reduction in irrigation volumes with controlled water stress have showed a mean reduction of ETc by 24% in both past and future scenarios (A1 and B2) (Table 7). Such a considerable reduction produces a water stress condition to the crop due mainly to a high environmental evapotranspiration demand during the spring-summer period.

Discussion

The increase in temperatures influences crop life cycles and forest species, and this causes a temporal tendency to anticipate the phenological phases (vegetative stage, flowering and maturation) with more risks for the return of low air temperature, and a different sensitivity to phyto-pathologies, changes in agro-techniques and variations of geographic areas of the species distribution.

The main effect on the crop productivity is depending on the reduced biomass accumulation and, as a consequence, the final yield decreases. Firstly, the results of the simulations here reported highlight how the crop cycle length varies as a function of the season in which the crop grows and as a function of the future scenario. In particular, the A2 scenario mainly influences the cycle length of the crops which develop during summer, whereas the B1 scenario has a greater impact on the crops which develop mainly in spring. In fact, passing from past to future scenario B1 related to the thirty-year period from 2070 to 2099, the crop cycle of artichoke which completes its cycle from summer to spring (in 340 days), and the crop cycle of asparagus which represents mainly a summer development (May - September), are reduced by 20% and 15%, respectively. On the contrary, compared to A2 scenario, the crop cycle of the potato is mainly reduced with B1 (by 17% *vs.* 7%), because the analyses of meteorological data highlight higher temperatures in spring time compared to the A2 scenario. In broccoli, slight variations come out since the crop cycle trend is relatively short (90 days) and does not allow to evaluate the effects of the increases in temperature which happen in autumn with the A2 and B1 scenarios.

Secondly, taken into account the irrigation variables, the simulations highlight that the crops develop part of their crop cycle in summer, in the future they will be subjected to water supplies which vary with the

Table 5. Simulations of the irrigation variables with past and future scenarios (A2 and B1) on asparagus.

	Scenario	Present		A2						B1					
	Years	1980-2005		2010-2039		2040-2069		2070-2099		2010-2039		2040-2069		2070-2099	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
100ET	ETc (mm)	680	20	652	23	624	25	611	28	662	21	630	23	626	21
	Irrigation														
(mm)	488	32	451	35	445	37	418	29	462	34	443	33	441	32	
	Irrigation (n)	21	1	19	1	18	1	17	1	20	1	19	1	18	1
	K_c	0.74	0.02	0.71	0.02	0.67	0.01	0.65	0.01	0.71	0.03	0.68	0.02	0.67	0.01
50ET	ET_c (mm)	587	26	561	36	515	33	512	38	564	31	521	33	521	24
	Irrigation (mm)	367	24	329	27	315	24	295	20	338	23	316	22	315	22
	Irrigation (n)	22	1	19	2	19	2	17	2	20	2	19	2	19	1

Table 6. Simulations of the irrigation variables with past and future scenarios (A2 and B1) on broccoli.

	Scenario	Present		A2						B1					
	Years	1980-2005		2010-2039		2040-2069		2070-2099		2010-2039		2040-2069		2070-2099	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
100ET	ET_c (mm)	140	12	151	15	153	16	170	17	145	14	142	15	137	13
	Irrigation (mm)	18	16	18	13	22	20	35	19	17	12	12	16	12	10
	Irrigation (n°)	0.9	0.8	0.9	0.7	1.1	1.0	1.8	1.0	0.8	0.6	0.6	0.8	0.6	0.5
	K_c	0.65	0.05	0.69	0.04	0.67	0.04	0.70	0.04	0.64	0.04	0.66	0.02	0.66	0.04
50ET	ET_c (mm)	137	13	150	14	151	18	165	20	143	14	138	17	136	13
	Irrigation (mm)	13	11	13	11	18	18	27	16	14	12	10	13	8	8
	Irrigation (n°)	1.3	1.1	1.3	1.1	1.8	1.8	2.7	1.6	1.4	1.2	1.0	1.3	0.8	0.8

Table 7. Simulations of the irrigation variables with past and future scenarios (A2 and B1) on potato

	Scenario	Present		A2						B1					
	Years	1980-2005		2010-2039		2040-2069		2070-2099		2010-2039		2040-2069		2070-2099	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
100ET	ET_c (mm)	413	9	403	9	407	6	413	10	404	9	394	7	391	14
	Irrigation (mm)	242	47	242	29	258	53	240	28	252	29	250	24	268	32
	Irrigation (n)	17	3	17	2	18	3	17	2	17	2	17	2	19	2
	K_c	0.78	0.04	0.76	0.04	0.77	0.03	0.77	0.02	0.76	0.04	0.77	0.03	0.77	0.03
50ET	ET_c (mm)	319	40	303	29	287	40	299	16	293	19	273	13	262	27
	Irrigation (mm)	142	24	137	15	130	20	127	15	135	16	124	15	138	10
	Irrigation (n)	14	2	14	1	13	2	12	2	14	3	13	2	14	2

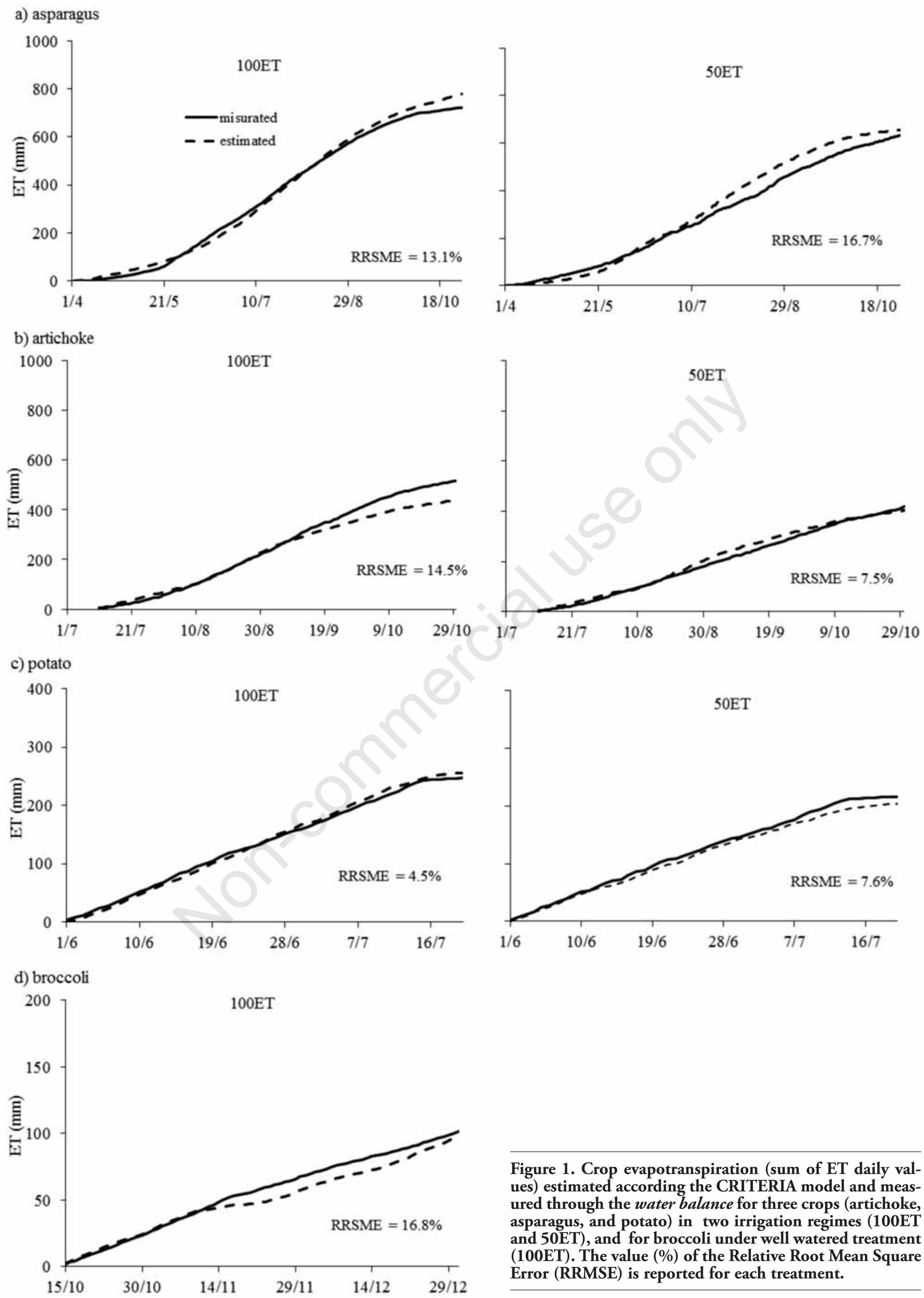

Figure 1. Crop evapotranspiration (sum of ET daily values) estimated according the CRITERIA model and measured through the *water balance* for three crops (artichoke, asparagus, and potato) in two irrigation regimes (100ET and 50ET), and for broccoli under well watered treatment (100ET). The value (%) of the Relative Root Mean Square Error (RRMSE) is reported for each treatment.

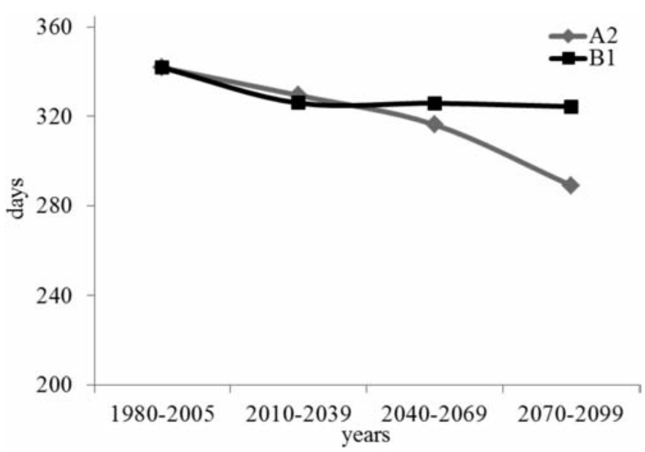

Figure 2. Artichoke: simulated values of the length of the crop cycle (in days) for scenarios A2 and B1.

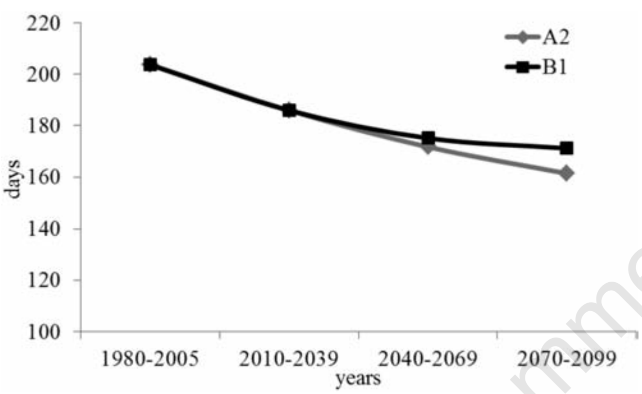

Figure 3. Asparagus: simulated values of the length of the crop cycle (in days) for scenarios A2 and B1.

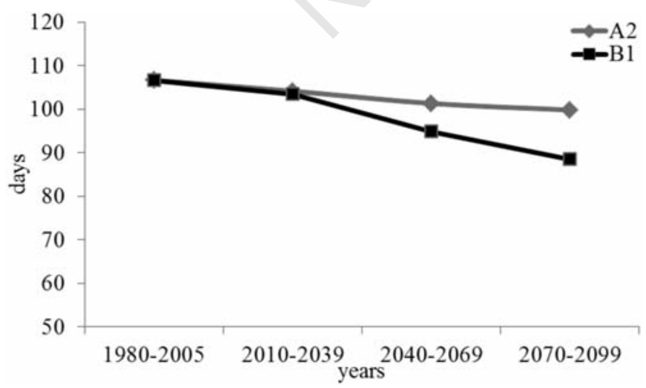

Figure 4. Potato: simulated values of the length of the crop cycle (in days) for scenarios A2 and B1.

type of scenario (A2 or B1). For example, in comparison with the simulations of the period 1980-2005, in the 2070-2099 the evapotranspiration of the artichoke will be reduced by 18% for A2 scenario and only by 3%, if it is taken into account B1 scenario. The seasonal irrigation volumes of artichoke reach a reduction of 24 and 15% in the thirty year period 2070-2099 respect to 1980-2005, according to the A2 and B1 scenario, respectively. In addition, the crops which develop their cycles in a period of the year with more probability of precipitation (spring and autumn) seem to be less subjected to future variations of the climate.

Thirdly, the simulations of A2 and B1 scenarios show how the deficit irrigation does not imply water stress conditions for the crops with summer crop cycle such as asparagus and artichoke, since it determines a reduction of ET lower than 15%. Instead, more attention needs to be taken into account for the application of the deficit irrigation on the crops which complete their cycles between spring and summer because stress conditions could happen, since a reduction of ET lower than 25% will occur. The controlled water stress, for annual crop such as broccoli, does not have an important influence because the effects of spare irrigations (1 or 2) are completely masked by the annual precipitations. These estimates provided by CRITERIA are exclusively related to crop water consumptions and not to productivity. Based on these results, in the future there will be less pressure from irrigated farming system on water resources. Nevertheless, it needs to be taken into account that a change in precipitation trend (reduction of rainy days associated to an increase in the intensity of events) could create superficial runoff phenomena and a low accumulation of water in the soil profile or in the ground water tables. As a consequence, there would be soil erosion and in all likelihood an increasing susceptibility to drought, especially in the late spring and summer periods (Imeson and Emmer, 1992; Christensen and Christensen, 2004).

Ultimately, a reduction of rainfalls in autumn-winter period provides less ground waters supply. Moreover, the increase in frequency and intensity of heat waves in the spring-summer period results in a greater occurrence of water stress which can not be restored by irrigation. Finally, a discontinuity of spring rainfalls originates more superficial runoff loss due to more frequent short and heavy storms. All these anomalies create the necessary conditions for an increasing likelihood of the susceptibility to drought and soil erosion.

Conclusions

This study has given the opportunity to improve the knowledge of future availability and use of water resources, to lay the basis for a sustainable use and for planning future efficiencies of irrigation systems for water conservation. In particular, the CRITERIA model, adaptable to any crop situation,. has been evaluated. Either on regional or farm scale, and with daily calculation, the mathematical simulations have allowed evaluating water supply with which it is possible to estimate the seasonal mean water volumes for different crops and irrigation systems. The modeling is at the bottom of a modern approach to study the relations between climatic changes and agriculture. The study has involved qualitative aspects of water for irrigation use for poly-annual (artichoke and asparagus) and annual (potato and broccoli) crops in anticipation of A2 and B1 future scenarios with CRITERIA model. Regarding the crop cycle length and the irrigation variables, it has been highlighted the ability of the model to define the possible future scenarios. Given the validity of the used approach, the methodology could be extended and adopted to other species. For this kind of applications, the results achieved with the scenarios have shown sensitivity to the difference between A2 and B1 scenarios.

It needs to be highlighted that the success of the simulation depends on the quality of data and the crops parameters. Therefore, it should be promoted the study of new technical agendas more corresponding to the future agriculture. Furthermore, the nowadays available crops' parameters do not take into account the development of new cultivated varieties with shorter cycle, more resistant to water stress and more efficient to water use. In addition, it is worth keeping in mind that the simulations reported in this study hypothesize the availability of water *on demand* and with unlimited quantity, even if it is regulated. On the contrary, a reduction of rainy days, which is commonly observed in the Mediterranean area, could cause a situation of water shortage, while an increase in temperatures registered in winter could be the cause of an early development of the phenophases of some cultures.

Therefore, regarding the aspects related to water resource, the agricultural sector could be strongly interested in the variation of the climatic, both for the reduction of soil water availability, the rate of water flows and the reserve of underground water, and for the increase of water supply of cropping species linked with the daily increase of evapotranspiration. Moreover, the increase in temperatures, the reduction in effective rainfalls and the early crop season, compared to normal climatic conditions, call for an early irrigation demand. The occurrence of these phenomena leads not only to an increase of water quantity, which is necessary for an adequate water supply to crops with spring-summer cycle, but also to the need of supplemental irrigations in winter and spring. From a territorial point of view, the irrigated areas, particularly the coastal ones which are supplied by the ground water tables, could be negatively influenced by the effects of climatic changes and also as a consequence of more competition with other sectors which use the same water resource. Ultimately, the internal areas too, included the hilly ones which generally are well supplied, during summer could be in very critical situations.

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