Climate change impact on crop rotations of winter durum wheat and tomato in Southern Italy: yield analysis and soil fertility

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Abstract

Cropping systems are affected by climate change because of the strong relationship between crop development, growth, yield, CO_2 atmospheric concentration and climate conditions. The increasing temperatures and the reduction of available water resources may result in negative impacts on the agricultural activity in Mediterranean environments than other areas. In this study the CERES-Wheat and CROPGRO-Tomato models were used to assess the effects of climate change on winter wheat (*Triticum durum* L.) and processing tomato (*Lycopersicon aesculentum* Mill.) in one of most productive areas of Italy, located in the northern part of the Puglia region. In particular we have compared three different General Circulation Models (HadCM3, CCSM3, ECHAM5) subjected to a statistical downscaling under two future IPCC scenarios (B1 and A2). The analysis was carried out at regional scale repeating the simulations for seven homogeneous area characterizing the spatial variability of the region. In the second part of the study, considering only HadCM3 data set, climate change impact on long-term sequences of the two crops combined in three crop rotations, were evaluated in terms of yield performances and soil fertility as indicated by the soil organic content of carbon and nitrogen. The comparison between GCMs showed no significant differences for winter durum wheat yield, while noticeable differences were found for yield and irrigation requirements of tomato. Under future scenarios, the production levels were reduced for tomato, whereas positive yield effects were observed for winter durum wheat. For winter durum wheat the simulation indicated that two- and three-year rotations, including one year of tomato cultivation, improved the cereal yield and this positive effect maintained its validity also in future scenarios. For both crops higher requirements of water and nitrogen were predicted under future scenarios. This result coupled with the decrease of yield caused negative reduction of water use efficiency and nitrogen use efficiency for tomato cultivation.

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Key words: DSSAT model, CENTURY-module, climate change, winter durum wheat, tomato, crop rotation.

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Introduction

Climatic variability plays an important role on agricultural productions with a significant impact on crop growth, development and yield, making the agriculture activity one of the most sensitive and vulnerable sectors among the anthropic activities.

The Fourth Assessment Report (AR4) IPCC's relates that continued greenhouse gases (GHG) emission might induce many changes in the global climate system during the 21th century that would be very likely larger than these observed during the 20th century (IPCC, 2007a).

Using of climate change scenarios, diffusively generated by GCM (General Circulation Model) simulations, was essential to climate change assessments on agricultural and water resources for the past 20 years. In fact, various future scenarios have been defined and reported in the SRES (Special Report Emission Scenarios) in order to describe the forecasted GHG emissions and the corresponding socio-economic development (IPCC, 2000). To evaluate climatic change impacts on agriculture it is necessary to use climate data at regional and daily scale. Several methods of downscaling based on GCM simulations are developed to accommodate these scale differences obtaining climate data on a finer scale that capture the effects of local and regional features in areas with complex surface physiography (Pizzigalli *et al*., 2012).

Because of the complexity of the soil-plant systems, some crop simulation models take into account several factors of crop-environment interactions and can predict quantitatively and qualitatively crop yields. DSSAT (Decision Support System for Agrotechnology Transfer; Jones *et al*., 2003) is an excellent example of decision support system that allows users to combine technical knowledge contained in crop growth models with economic considerations and environmental impact assessments (Jame and Cutforth, 1996). DSSAT allows to simulate long-term crop rotation or sequence under different climate scenarios by means of *Sequence* option that permits to evaluate the effects of rotation on crop yield, soil, water and nutrient status (Thornton *et al*., 1994). Thanks of the linkage of DSSAT with a Geographic Information System (GIS), the model can also carry out productivity analysis at regionally scale. In fact, several studies have been carried out to examine cropping systems at spatial scale (Rinaldi and Borneo, 2001; Heinemann *et al*., 2002; Guereña *et al*., 2001; Luo *et al*., 2003; Rinaldi *et al*., 2007; Giglio *et al*., 2010).

Changes in global average temperature, precipitation regime and increase of atmospheric CO_2 concentration will impact the crop productions at various rates in different parts of the world with consequences related to food supply and demand (Rosenzweig and Parry *et al*., 1994; Olesen and Bindi, 2002; Parry, 2004; Lee, 2009). Furthermore, despite new technologies and introduction of new crop variety, climate will continue to be a predominant effect on the yield response of the crops.

Particularly in the Mediterranean area, already considered as one of the most critical and vulnerable geographic zone, the global warming phenomenon, concerning both the climate characteristics like temperature and precipitation pattern, could affect the water availability and irrigation requirements due to significant variations of evapotraspiration rates, runoff, infiltration and soil moisture temporal dynamics. In fact, the IPCC report (IPCC, 2007a) shows as that Mediterranean climate could be interested by a greater increase of temperature, especially in the summer months although the predictions of rainfall are more uncertain and differentiated on basis of the relationships between local factors as geographic features and land use. Certainly environmental modifications, especially soil moisture and air condition variations have strong influence on the most important plant physiological processes (photosynthesis, transpiration, respiration and partitioning of photosynthesis products). Many studies researches have been carried out to predict the impacts of climate change on crop productivity and to estimate the vulnerability degree of most important crops as wheat, corn, soybean (among others, Alexandrov 1997; Alexandrov and Hoogenboom, 2000; Eitzinger *et al*., 2003; Ventrella *et al*., 2008; Guo *et al*., 2010). Moreover, modifications of these processes can require the individuation of management practices in order to adapt the cropping systems to the forecasted climate condition. Such an optimization can interest important agronomic practices at farm level as crop and/or variety choice, sowing/transplantig time, crop rotation, fertilization, irrigation, wedding control, etc. Ventrella *et al.* (2011) used the cropping system models CERES-Wheat and CROPGRO-Tomato of DSSAT to analyse the response of winter durum wheat and tomato crops to climate change, irrigation and nitrogen fertilizer managements.

Among the agronomical practices, crop rotation allows to preserve agronomic and environmental sustainability by using more efficiently natural resources and give, in most case, higher crop yields than these obtained in monoculture. Sequence of various crops, other than to avoid the build-up of pathogens and pests problems, is considered to be an useful technique to conserve and to improve soil structure and fertility. On the other hand, the adoption of cereal rotations with other crops, especially with legumes, and incorporating of crop residues, can reduce the amount of mineral nitrogen fertilizers applied to the soil (Shah *et al*., 2003).

The interest of this study is focused on *Capitanata area*, a plain of about 4000 km^2 located in the northern part of the Apulia Region in southern Italy. Such area is characterized by farms with average size up to 20 ha, highly productive soils cultivated in intensive and irrigated regime. The winter durum wheat (*Triticum durum* L.) represents the principal cereal crop often grown in rotations with irrigated horticultural species. Among these, processing tomato crop (*Lycopersicon aesculentum* Mill.) is well represented. In particular, two-years rotation (tomato-wheat) and three-years rotation (tomato-wheat-wheat) are the typical farming rotations of this large productive area.

Our interest was, firstly, to evaluate winter durum wheat and tomato responses under future climatic scenarios as generated by three different climate GCMs (HadCM3, CCSM3, ECHAM5) trough a space-temporal analysis for seven pedologic homogeneous areas characterizing the spatial variability of *Capitanata* plain. In a second step, only climatic scenarios derived from HadCM3 model were used to compare different hypothesis of crop sequences based on cultivation of winter durum wheat and tomato. The analysis included productive parameters, some water balance components and soil organic matter temporal evolution.

Materials and methods

Study area

The *Capitanata* plain is delimited by the Apennines Chain at West and by Gargano promontory at East and is mainly constituted by continental and fluvial sediments and some terraced marine deposits of Pliocene and Pleistocene ages. The climate of this zone is classified as climate *Accentuated Thermo-Mediterranean* (UNESCO-FAO), with winter characterized by temperatures that also descend below 0°C and hot summer with temperature that can exceed 40°C. The annual precipitations range between 400 and 800 mm, mostly concentrated in winter months.

Seven homogeneous pedologic areas represent the soil data model inputs (Figure 1a). For each homogeneous area considered, a specific

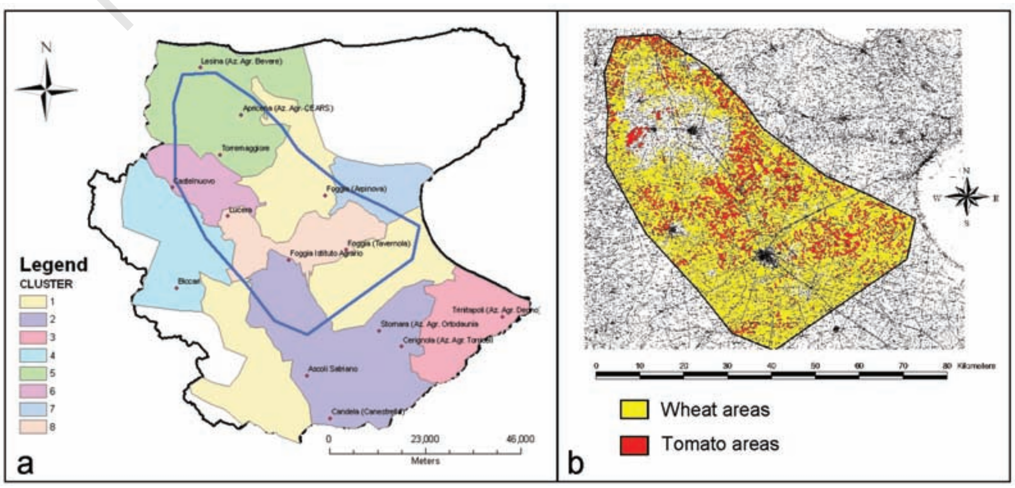

Figure 1. Homogeneous pedologic areas in *Capitanata* plain (a); Soil use map (b).

pedologic profile was individuated applying a clustering procedure and a subsequent interpolation of soil data by geostatistical techniques (Castrignanò *et al*., 2010). Soil profile for each area was subdivided in two layers (0-40 and 41-80 cm) and described by some measured characteristics (texture, soil organic carbon, cation exchange capacity, pH in water) and hydrological parameters (soil water holding and conductivity), calculated by means of pedotransfer functions implemented into the DSSAT model. Figure 1b shows land use map related to the cultivation of winter durum wheat and tomato. Such map was obtained combining spectral and spatial information relative to the area of study. Fiorentino *et al*. (2008) integrated a special classifier of remote sensed data, derived from interpretation of Landsat TM image collected in July 2006, with the spatial information provided by a geostatistical tool as *Indicator Kriging* algorithm. Some areas, not be classified due to clouds cover, were considered using informations of soil classes as indicated in the SIGRIA CASI 3 Project (INEA, 2001). According to such analysis the winter durum wheat was potentially cultivated in the 90% of polygons while the remaining 10% interested the cultivation of tomato.

Climatic scenarios

Two IPCC future climate scenarios (B1 and A2) were used in order to evaluate the impact of future climate change, taking into account the progressive increase of atmospheric CO_2 concentration, respect to the pre-industrial level. The alternative climate projections used in this study were the output data of three GCMs: Hadley Centre Coupled Model version 3 (HadCM3), NCAR's Community Climate System Model version 3 (CCSM3) and a model referred to Max Planck Institute for Meteorology of Hamburg - DE (ECHAM5), as described by Pizzigalli *et al*. (2012) and Rinaldi and De Luca (2012). The local interest of this study imposed to use of regional downscaled data at daily temporal scale. A statistical downscaling procedure was conducted using the stochastic weather generator LARS WG, that was calibrated including statistics and changes in mean climate, as derived from GCM, and integrated with the statistics of historical climatic series collected at the experimental farm of Agricultural Resource Council (CRA) at Foggia (Pizzigalli *et al*., 2012). The obtained future climate scenarios were divided in three time slices (I: 2011-2040; II: 2041-2070 and III: 2071-2100) and compared to a generated baseline scenario (1951-2005). In the second part of this study, only A1 and B2 scenarios generated from HadCM3 were considered to assess the future climate change impacts.

Crop models and management

DSSAT is a cropping system model allowing to predict and interpret the behaviour of the agronomic system for given condition, reducing the time and human resources necessary to find problem solutions and to evaluate alternative decision in agriculture (Tsuji *et al*., 1998). The model is characterized by a modular structure that facilitates its maintenance and permits the inclusion of additional components to simulate cropping system over a wide range of soils, climate and management conditions (Porter *et al*., 2000; Jones *et al*., 2003). The DSSAT is a collection of crop simulation models (for more than 20 crops) combined with various module for weather, soil water, soil dynamic, soil temperature, soil nitrogen and carbon and also crop management modules (including planting, harvesting, irrigation, fertilizer and residue). All modules operate together and the crop simulation model is the centre (Tsuji *et al*., 1998; Hoogenboom *et al*., 2004). CERES-wheat and CROPGRO-tomato are crop growth models embedded in DSSAT (Jones *et al*., 2003) that are able to predict the performance of wheat and tomato, respectively. CERES-wheat was tested in different sites in the world (Semenov *et al*., 1996; Alexandrov, 1997; Eitzinger *et al*., 2003; Lhomme *et al*., 2009; Pathak and Wassmann, 2009; Ventrella *et al*., 2009; Guo *et al*., 2010). However, CROPGRO model initially was developed for legumes (Boote *et al*., 1998; Hoogenboom *et al*., 1994), successively was adapted to tomato. Rinaldi and Ubaldo (2007), Rinaldi *et al*. (2007) and Giglio *et al*. (2010) applied such model for tomato cultivation. Both cropping system models have been calibrated and validated, at the selected area and for the two crops object of this study, by using experimental data collected in experimental trials conducted in a farm of CRA at Foggia (Wheat: cv Simeto, Rinaldi, 2001; Tomato: variety PS 1296, Rinaldi *et al*., 2007). The soil water balance, developed according to the cascading method or the *tipping bucket* approach, include precipitation, infiltration, transpiration, soil evaporation, drainage from the soil profile and crop water uptake parameters; whereas potential evapotraspiration is calculated using modified version of Priestley Taylor (1972) method. In addition, through the organic matter turnover, the crop models evaluate carbon and nitrogen balances providing feedback that influences various growth and development processes. The CENTURY-based module, used in this study, was adapted by Gijsman *et al*. (2002) and integrated into the DSSAT structure (Jones *et al*., 2003) to facilitate the simulation of potential soil organic carbon sequestrations in crop rotations, initializing soil carbon and other variables only at the start of the simulations. The incorporation of the CENTURY-based module has make DSSAT more flexible in handling different agricultural systems and more suitable for long-term simulations.

The main crop management practices, reported in Table 1, were scheduled to preserve optimum conditions according to the agronomic practices currently adopted in the *Capitanata* plain. For tomato growth automatic irrigation was adopted, setting a drip irrigation method, with water amount refilling up to 80% of field capacity and irrigation with the soil moisture falling to 60% of field capacity.

The AEGIS/WIN option, as described by Engel *et al*. (1997), was applied with polygons derived by the intersections of soil and land-use as reported in Figure 1 for winter durum wheat and tomato. The simulation outputs were also displayed in thematic digital maps for better visualization of spatial analysis (*data not shown*).

For the each homogeneous areas, the *Sequence* option was used in order to simulate a two-years (wheat-tomato) and a three-years (wheat-wheat-tomato) crop rotations, compared to a continuous cultivation of wheat.

Table 1. Crop management of winter durum wheat and tomato.

Management Sowing/transplanting	Winter durum wheat 26th November	Tomato 30th April
Fertilization		
N	60 kg ha^{-1} as diammonium phosphate (pre-sowing) 60 kg ha^{-1} as ammonium nitrate (top dressing)	100 kg ha^{-1} as diammonium phosphate (pre-transplanted) 100 kg ha^{-1} as ammonium nitrate (top dressing)
Crop residues	Incorporation	Incorporation
Irrigation	Rainfed	Automatic
Harvest	At maturity	At maturity

Results and discussion

Climate data analysis

Compared to Baseline, in B1 scenario the mean annual (T_{avg}) was projected to increase from 0.8°C to 1.6°C from 2011 to 2100. A similar trend was also observed for the annual T_{avg} in A2 scenario but with higher values ranging from 0.7°C to 2.7°C. Instead, an increase in rainfall was predicted of about 5 and 9% for B1 and A2 scenarios, respectively, without particular temporal trend (Table 2).

Crop vulnerability to climate change and GCMs comparison

The dry matter grain yield of winter durum wheat was about 3.60 t ha^{-1}. Under the forecasted climate scenarios, a slight increase of 4% was observed in average without significant differences due to the effect of different GCMs but also of IPCC scenarios (Figure 2), in agreement with the results obtained by Guo *et al*. (2010) as a consequence of a overall effect due to increasing temperatures, raising CO_2 and with no significant variations of annual precipitation.

Other studies reported that elevated CO_2 concentration can have considerable effects on wheat yield (Reyenga *et al*., 2001; Weiss *et al*., 2003). However, Rosenzweig and Tubiello (1996) found inconsistence in wheat yield changes under doubling of CO_2 and a rise in daily average temperature. Haim *et al*. (2008) excluded the effect of CO_2 fertilization on wheat yield to avoid the uncertainty when combined with other environmental parameters.The behaviour of tomato crop, cultivated in the spring-summer period, was completely different if compared to winter durum wheat with the forecasted increase of seasonal temperature affecting negatively the crop performances. In particular, results reported in Figure 3 shown that the reference dry matter fruit yield simulated for tomato in Baseline period was 11.73 t ha^{-1}. Under future climate, yield decreased slightly in the first and second 30-year periods (-6%), and strongly in the last 30-year period (from 2070 to 2100) (-24%). In particular, under A2 scenario of HadCM3, a more significant decrease of tomato yield (-38%) was predicted during the third 30-year period. This large yield decline was due to the greater temperature increase observed in the future scenarios respect to the Baseline during growth season (April-August) and in particular during the reproductive stage with negative consequences in the development rate and the photosynthates translocation into the fruits. Such significant decrease of tomato dry matter yield due to the rising temperature was not fully offset by the positive effect expected by increasing CO_2. The results of irrigation requirement, simulated only for tomato under different climate change scenarios compared with the baseline period, are reported in Figure 4 showing an average value of about 310 mm for the Baseline scenario. Due to different rainfall distribution and evaporative demand of the atmosphere simulated by CGMs, significant differences were observed with the HadCM3 predicting seasonal irrigation higher than those of the other GCMs with increments ranging from 5-15% (Figure 4).

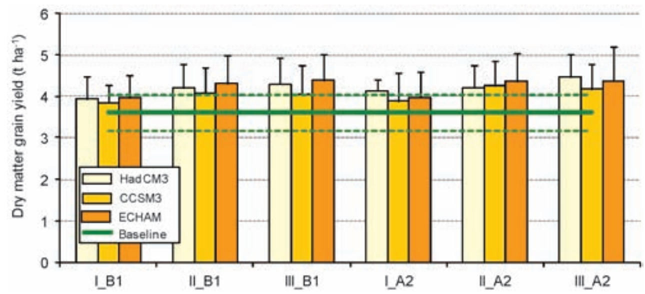

Figure 2. Comparison between output of dry matter grain yield of winter durum wheat obtained using three future climatic models (during three 30-year periods) and Baseline scenario.

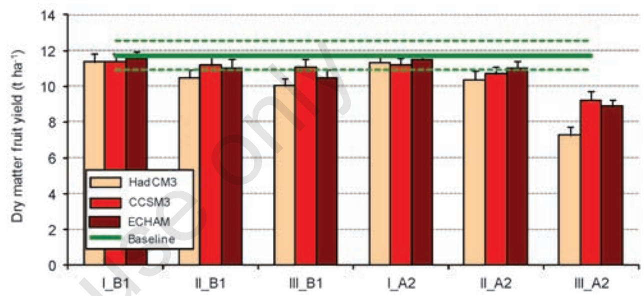

Figure 3. Comparison between output of dry matter fruit yield tomato obtained using three future climatic models (during three 30-year periods) and Baseline scenario.

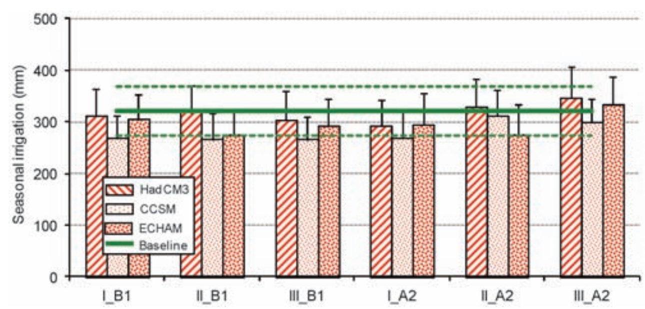

Figure 4. Comparison between output of tomato seasonal irrigation simulated using three future climatic models (during three 30-year periods) and Baseline scenario.

Table 2. Baseline scenarios and change of temperature and precipitation under B1 and A2 scenarios and atmospheric CO_2 concentration.

	Precipitation (mm)	T_{avg} °C	CO_2	B1 Precipitation (Δ %)	T_{avg} Δ°C	CO_2	A2 Precipitation (Δ %)	T_{avg} Δ°C	CO_2
Baseline	632	15.5	360						
2011-2040				4.7	0.80	400	10.5	0.68	400
2041-2070				4.9	1.26	500	8.3	1.58	550
2071-2100				5.7	1.63	550	9.7	2.71	750

Cropping systems simulations adopting HadCM3 model outputs

The results discussed in this section are those obtained by considering only HadCM3 and adopting the sequence option of DSSAT in order to evaluate the effects of crop rotation, climate change, spatial variability and their interactions on winter durum wheat and tomato productivity. Also in this case, the average yields of winter wheat and tomato simulated under Baseline scenario were comparable to those generally obtained in the study area of *Capitanata*.

Winter durum wheat

All the parameters analysed revealed that the effects of crop rotation, climate change, spatial variability, as well as their respective interactions, were highly significant (Table 3). Crop rotation showed that the two-year and three-year rotations increased the winter durum wheat yield of about 20 and 10%, respectively, compared to the durum wheat monoculture. The same trend was observed for crop evapotranspiration (ET), water use efficiency (WUE) and Nitrogen (N) uptake. Changes in temperature, precipitation and CO_2 concentration were predicted to increase the grain yield of about 15% and 20% under B1 and A2, respectively, with the same trends also for the other parameters with the exception of harvest index (HI) that showed small variations. Such last result can be attributed to a lower increment of total biomass respect to that of grain yield.

The spatial variability, as represented by the 7 homogeneous areas, was the factor variability with the lowest variations for the all parameters (Table 3). When crop rotation and climate scenario in the Baseline and future periods were considered the trends, just observed as main effects, were confirmed with the highest yield characterizing the two-year rotation and the future scenario. In particular, the mean grain yield in one-year rotation was always lower than 4 t ha^{-1}, confirming the validity to adopt crop rotations including the irrigated tomato. Moreover, regardless of crop rotation, the wheat yield was predicted to increase almost linearly during the future study period. A particularly high increment (more than 20%) was observed in the first 30-year period compared to the Baseline one when the three-year rotation was considered (Figure 5).

Durum wheat seasonal evapotraspiration was predicted to increase for all crop rotations during the future periods compared to the Baseline one either for A2 and B1 scenarios (Figure 6). This finding that would lead to increase evapotranspiration, exceeding an average value of 400 mm, is due to highest evaporative demand of the atmosphere caused by the rise of temperature during the spring months.

Also the durum wheat N uptake was predicted to increase during the future period and in particular for the two-year and three-year rotation with values higher than 150 kg ha^{-1} (Figure 7).

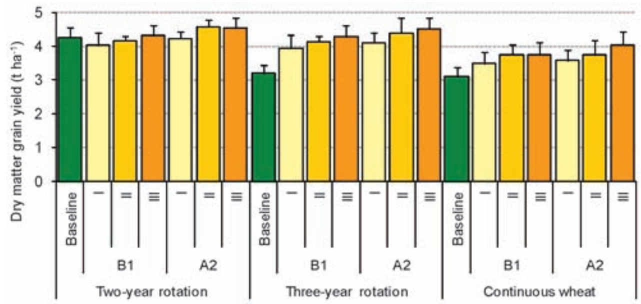

Figure 5. Effects of interactions between climatic scenarios and crop rotations on dry matter grain yield of winter durum wheat.

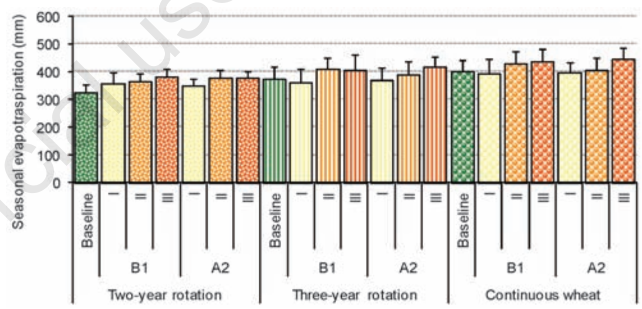

Figure 6. Effects of interactions between climatic scenarios and crop rotations on seasonal evapotranspiration of winter durum wheat.

Table 3. Results of main effects, as average ± standard deviation, on winter durum wheat parameters simulated by CERES-wheat model.

	Yield (t ha^{-1})	HI	ET (mm)	WUE (kg m^{-3})	Nitrogen uptake (kg ha^{-1})
Crop management					
One-year rotation	3.58±0.46	0.39±0.05	415±46	0.87±0.12	132±13
Two-year rotation	4.30±0.33	0.39±0.04	359±35	1.21±0.14	158±09
Three-year rotation	3.99±0.57	0.40±0.05	388±49	1.04±0.17	147±17
Climate					
Baseline	3.41±0.49	0.39±0.05	374±50	0.93±0.24	129±18
B1	3.92±0.42	0.39±0.05	401±52	0.99±0.16	144±13
A2	4.11±0.48	0.40±0.04	398±46	1.05±0.18	149±16
Areas					
Area 1	3.95±0.53	0.40±0.05	394±50	1.02±0.19	146±16
Area 2	3.84±0.55	0.39±0.05	391±49	1.00±0.20	141±17
Area 4	3.82±0.56	0.40±0.05	391±51	0.99±0.20	141±17
Area 5	3.77±0.58	0.40±0.05	389±51	0.99±0.20	138±18
Area 6	3.89±0.55	0.39±0.05	398±50	0.99±0.19	142±13
Area 7	3.96±0.52	0.39±0.05	396±50	1.02±0.19	145±16
Area 8	3.90±0.53	0.39±0.05	397±49	1.00±0.19	143±17

HI, harvest index; ET, evapotraspiration; WUE, water use efficiency; all the effects, as well as their respective interactions, are highly significant.

Tomato

All the parameters analysed revealed that the effects of crop rotation, climate change and spatial variability, as well as their respective interactions, were highly significant as reported for durum wheat. However, the two-year rotation improved tomato yields by only 4% compared to the three-year rotation (Table 4). The only exception was related to N uptake that showed a reduction of about 12% in the three-year rotation because of a likely higher N uptake of winter durum wheat which could require an higher N fertilization than that planned in the carried out simulation. The spatial variability slightly affected the tomato parameters with the exception of N uptake that showed variation up to 13% due to the different nitrogen availability that characterize the seven soil (Table 4). Under the future climate scenarios, the model simulated negative effects on tomato yield. A decrease in fruit dry matter of 40% and 46% approximately was detected in the B1 and A2 scenarios, respectively. Similar trends were also observed for HI and WUE. Moreover, an increase of ET and N uptake was predicted for future scenarios but with variations that did not exceed 5% (Table 4). Figure 8 shows the effects of the interaction *Climate x Crop rotation* on tomato fruit yield. The Baseline dry matter fruit yield predicted for tomato cultivated in two-year rotation was about 14 t ha^{-1}, while, in three-year rotation such parameter dropped to 12 t ha^{-1}. Under future climate, yield was predicted to decrease over all in the last 30-year period of this century taking lower values about 6 and 4 t ha^{-1} under B1 and A2 scenarios, respectively, regardless of crop rotation. The reference irrigation requirement for tomato was about 350 mm. No large differences were predicted when the tomato was included in the two-year rotation. However, DSSAT simulated decreasing irrigation requirements in the future study period up to 250-300 mm when tomato was cultivated in 3-year rotation (Figure 9). This result is probably due to residual effects of soil water content at transplanting time of tomato when the three-year rotation was adopted

The simulation of N uptake highlighted an increase that characterize the two-year rotation compared to the Baseline with the N uptake reaching the threshold value of 500 kg ha^{-1} under A2 scenario (Figure 10). The strong increase of N uptake coupled with equally strong reduction in yield caused a consequent a sharp reduction in nitrogen use efficiency.

Soil organic matter trends

DSSAT with the CENTURY-module displays a greater flexibility in handling different agricultural systems and has become more suitable for long-term simulations (Gijsman *et al*., 2002).

Figures 11 and 12 report the temporal evolution of total soil organic carbon (C) and total soil organic nitrogen during the study period

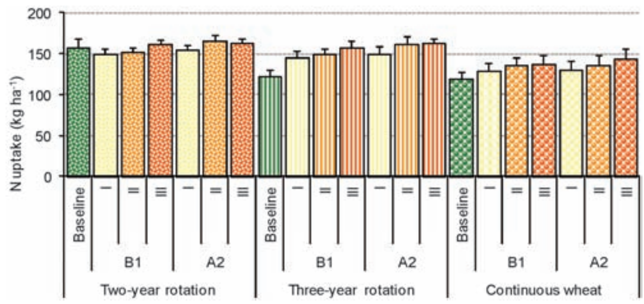

Figure 7. Effects of interactions between climatic scenarios and crop rotations on seasonal N uptake of winter durum wheat.

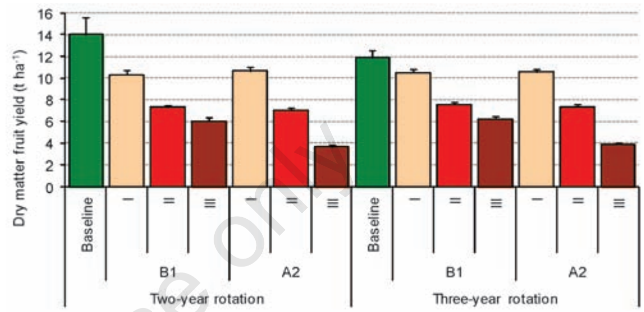

Figure 8. Effects of interactions between climatic scenarios and crop rotations on dry matter fruit yield options of tomato.

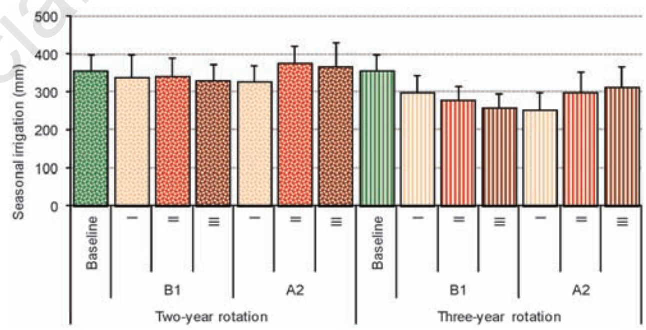

Figure 9. Effects of interactions between climatic scenarios and crop rotations on seasonal irrigation of tomato.

Table 4. Main effect results, as average ± standard deviation, on tomato parameters simulated by CROPGRO-tomato model.

Tomato	Yield (t ha^{-1})	HI	ET (mm)	WUE (kg m^{-3})	Nitrogen uptake (kg ha^{-1})
Crop management					
Two-year rotation	8.99±3.59	0.53±0.13	817±59	1.12±0.46	465±71
Three-year rotation	8.61±2.76	0.55±0.14	814±52	1.07±0.36	409±58
Climate scenarious					
Baseline	13.16±1.68	0.70±0.13	809±48	1.63±0.22	424±75
B1	7.91±1.80	0.52±0.04	813±53	0.98±0.26	444±62
A2	7.09±2.81	0.46±0.05	822±64	0.89±0.39	452±76
Areas					
Area 1	8.80±3.45	0.54±0.14	816±57	1.10±0.45	486±62
Area 2	8.88±3.24	0.54±0.13	813±56	1.11±0.42	421±59
Area 4	8.80±3.22	0.54±0.13	816±57	1.09±0.42	430±71
Area 5	8.75±3.11	0.54±0.13	816±57	1.09±0.41	406±71
Area 6	8.84±3.31	0.54±0.14	816±57	1.10±0.43	443±74
Area 7	8.86±3.42	0.54±0.14	816±57	1.10±0.44	476±64
Area 8	8.88±3.30	0.54±0.13	816±57	1.10±0.43	436±62

HI, harvest index; ET, evapotraspiration; WUE, water use efficiency; all the effects, as well as their respective interactions, are highly significant.

under Baseline and future scenarios for the three crop rotations. The higher values of soil organic C and N were observed in two- and three-year crop rotations than in the durum wheat monoculture. This trend was evident over the years of the Baseline scenario and continued in the future scenarios. The higher C and N soil content in the two-year rotation can be attributed to the higher production of crop tomato residues that characterized this rotation compared to the other ones. In particular, the tomato returning most frequently on the soil increased the biomass useful for humification processes.

In the Baseline scenario and during the first ten years, C and N contents increased in all crop rotations. After this period, the contents of C stabilized around 130 t ha^{-1} while those of the two- and three-year rotation continued to increase up to 140 t ha^{-1}. Such values remained almost constant for the next 40 years and then began to decrease reaching new steady-state values at the end of the century (between 120 and 130 t ha^{-1} of C soil, Figure 11). Such decline of C content during future scenarios can be attributed to the higher temperature that increased the degradation of the soil organic C. Figure 12, related to soil organic N, showed the same temporal evolutions but with larger differences depending on crop rotations.

In future scenarios, applying the rotation techniques, trends of soil C and N content, slightly ascend until the first 30-year period, successively decrease progressively during the second and the third 30-year periods, reaching values more lower than observed in the baseline only for soil C content.

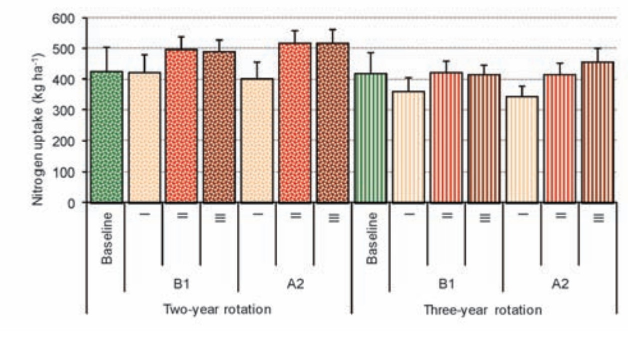

Figure 10. Effects of interactions between climatic scenarios and crop rotations nitrogen uptake of tomato.

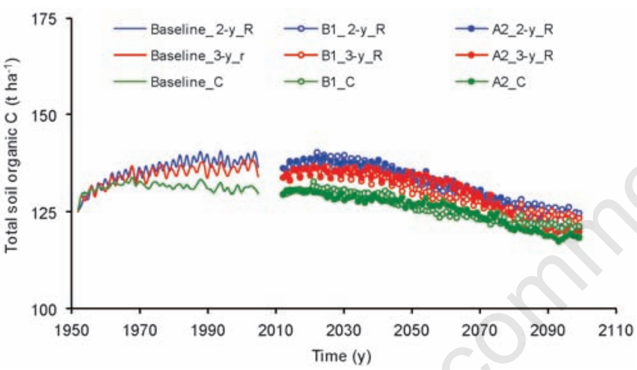

Figure 11. Total soil organic carbon trends considering for crop rotations (C = continuous wheat; 2-y_R = two-year rotation; 3-y_R = three-year rotation) under climate scenarios (Baseline, B1 and A2).

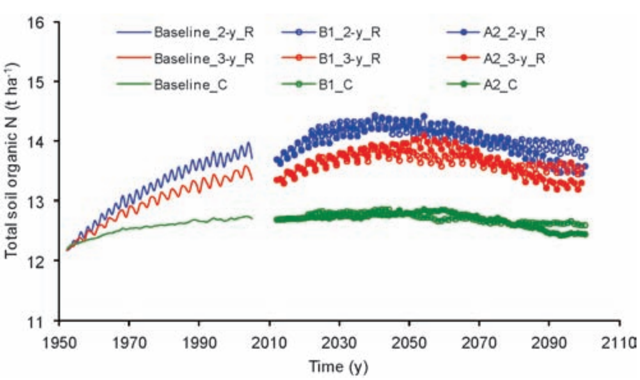

Figure 12. Total soil organic nitrogen trends considering for crop rotations (C = continuous wheat; 2-y_R = two-year rotation; 3-y_R = three-year rotation) under climate scenarios (Baseline, B1 and A2).

Conclusions

Climate change impact is today a basic concern of great interest at local and international levels. The combination of generated climatic scenarios with crop simulation models, represents operative tools able to project hypothesis for the future and improving the research capability. The comparison between GCMs showed no significant differences for winter durum wheat yield, while noticeable differences were found for the tomato yield and irrigation requirements. The differences between winter and summer crops on the fitting capacity respect to climate change depended on the timing and the duration of vegetative and reproductive phases that were determinant for yield. The simulations for winter durum wheat showed that, under future IPCC scenarios, the positive fertilization effect of increasing CO_2 concentration on yields was greater than the negative effects due to rising temperature and variation of rainfall. These results were in agreement with those reported in the FAR-IPCC report (IPCC, 2007b). For winter durum wheat the simulation highlighted that two- and three-year rotations including one year of tomato cultivation had positive effects on the cereal performances and these effects maintained their efficacy also in future scenarios. However, higher productions of durum winter wheat as simulated during future scenarios and with two-year rotation resulted in greater requirements in terms of both water transpirated and N uptake.

Instead, for tomato the positive effect of increasing CO_2 concentration was not sufficient to overcome the negative effects due to increasing temperatures. These results confirm that summer crops, including tomato, may be strongly affected by climate change. The modification of present crop rotations was found to be not effective enough to reduce the negative effects of climate change even if positive effects were found for maintaining or increasing the soil organic carbon and nitrogen content. Even for the cultivation of tomato, but despite the lower production as forecasted for this crop under future scenarios, the requirement of water for evapotranpiration and nitrogen uptake increased compared to Baseline scenario with consequent negative reductions of water use efficiency and nitrogen use efficiency.

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