IMPACT OF DIFFERENT CLIMATE CHANGE SCENARIOS ON RAINFED CROPPING SYSTEMS IN CENTRAL ITALY

IMPATTO DI DIFFERENTI SCENARI DI CAMBIAMENTO CLIMATICO SU SISTEMI COLTURALI IN ASCIUTTO DEL CENTRO ITALIA

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Abstract

The rainfed cropping system based on the durum wheat-sunflower rotation is very common in Central Italy, to the point of being the almost exclusive system in some areas. The predominance of the system, and the suboptimal environmental conditions in which such system is implemented make it at risk in scenarios of possible worsening of weather patterns as estimated by weather change scenarios. The objectives of this paper were: 1) to estimate the impact of climate change on the agronomic performance and long term soil fertility; 2) to explore adaptation strategies and to identify research needs. Three years of field data on current cropping system practices were collected at two microcatchments of the Marche (Central Italy) to calibrate the cropping systems simulation model CropSyst. Crops yield and soil organic matter dynamics were analyzed in relation to increased air temperature and CO_2 concentration, as forecasted by different future climate scenarios.

To assess the impact of climatic change on mean crop yields and variability, two fifty-years *equilibrium* climate datasets were generated from a local 20-years daily temperature and rainfall dataset assuming for each scenario constant climate at different atmospheric CO_2 concentration: "baseline" $[CO_2]$ = 350 ppm; 2040 *equilibrium* $[CO_2]$ = 450 ppm. To assess the long term impact of climatic change on soil organic matter content, three 100-years *transient* climatic scenarios were generated from a 20-years daily temperature and rainfall dataset of a neighbouring station: *transient* "baseline" scenarios with current $[CO_2]$ = 350 ppm; *transient* "A2" and "B2" scenarios, characterised by an yearly increase of $[CO_2]$ starting from current conditions to final values of 840 and 620 ppm respectively.

Under 2040 *equilibrium* scenario, sunflower showed a slight increase of mean grain yield +12%, while durum wheat grain yield was not significantly different from "baseline". Under "baseline" *transient* scenarios and starting from a current soil organic matter content of 0.9%, CropSyst simulated a progressive decrease of soil organic matter down to 0.6% after 100 years. Under "B2" and "A2" scenarios, increased soil temperature simulated by CropSyst resulted in a sharper decrease of the soil organic matter, leading respectively 0.5% and 0.4% after 100 years. Results suggest that while climate change impacts on current rainfed cropping systems of central Italy may not be visible in the short term on crop yields, long term sustainability is expected to decline noticeably, even under "baseline" climatic scenarios. In terms of bio-physical research, further efforts should be addressed on the relationships between agronomic practices and seasonal dynamics of soil organic matter mineralization due to soil temperature.

Keywords: CropSyst, durum wheat, sunflower, adaptation, cropping system, sustainability.

Riassunto

Il sistema colturale asciutto basato sull'avvicendamento frumento duro-girasole è molto comune in Italia centrale, al punto di essere quasi esclusivo in alcune aree. La predominanza del sistema e le condizioni ambientali subottimali in cui esso è adottato, lo rendono vulnerabile nell'ipotesi di peggioramento delle tendenze climatiche, secondo quanto previsto dagli scenari di cambiamento climatico. Gli obiettivi di questo lavoro sono stati: 1) stimare l'impatto dei cambiamenti climatici su rese colturali, bilancio idrico e fertilità del suolo a lungo termine; 2) esplorare strategie di mitigazione e indirizzare ulteriori ricerche. Sono stati raccolti tre anni di dati sulle pratiche colturali adottate in due microbacini delle Marche per calibrare il modello di simulazione dei sistemi colturali CropSyst. Rese colturali e dinamica della sostanza organica sono state analizzate in relazione alla dinamica di temperatura dell'aria e concentrazione di CO_2 *prevista da differenti scenari climatici futuri.*

Per valutare l'impatto dei cambiamenti climatici su medie e variabilità delle rese colturali, sono stati generati due scenari climatici equilibrium *di cinquanta anni a partire da una serie reale di dati giornalieri di temperatura e precipitazione, assumendo per ogni scenario clima costante e differenti concentrazioni atmosferiche di* CO_2*: "baseline"* $[CO_2]$ *= 350 ppm; 2040* equilibrium $[CO_2]$ *= 450 ppm.*

Per valutare l'impatto a lungo termine del cambiamento climatico sul contenuto di sostanza organica a partire da venti anni di dati giornalieri di temperatura e precipitazioni di una stazione meteorologica vicina, sono stati generati tre scenari climatici transient*: lo scenario "baseline", con [CO_2] attuale = 350 ppm; gli scenari* transient *"A2" e "B2", caratterizzati da un progressivo incremento di [CO_2] da 350 ppm fino 840 e 620 ppm rispettivamente.*
Nello scenario equilibrium *2040, la resa del girasole ha mostrato un leggero incremento (+12%), mentre quella del frumento duro non è stata significativamente differente dal "baseline". Nello scenario* transient *"baseline", partendo da un contenuto attuale di sostanza organica nel suolo di 0.9%, CropSyst ha simulato un progressivo declino della sostanza organica, fino a 0,6% dopo 100 anni. Negli scenari "B2" e "A2", gli incrementi di temperatura del suolo simulati da CropSyst hanno favorito l'ulteriore diminuzione di sostanza organica, rispettivamente fino a 0,5% e 0,4% dopo 100 anni.*
Mentre l'impatto a breve termine dei cambiamenti climatici sulle rese degli attuali sistemi colturali in asciutto del centro Italia non appare determinante, la loro sostenibilità di lungo termine sembra essere in pericolo anche nello scenario "baseline". Ulteriori sperimentazioni di campo sono necessarie per validare le relazioni tra pratiche agricole e dinamiche stagionali della mineralizzazione della sostanza organica legate alla dinamica della temperatura del suolo.

***Parole chiave**: CropSyst, frumento duro, girasole, adattamento, sistemi colturali, sostenibilità*

Introduction

Future climate dynamics are a major source of uncertainty for future human activities and particularly for farming (IPCC, 2001; Moore, 2001). There is increasing need to develop a range of site specific options for the adaptation of cropping systems to future climate scenarios. While some key interactions between weather scenarios at elevated CO_2 effects and crop management, especially irrigation and fertilization regimes, are fairly well understood (Tubiello *et al*., 2007), the assessment of the impact of elevated CO_2 and temperature on crop yields and especially the implications for the long term sustainability of cropping systems is still largely uncertain. In fact there are thousands of chemical, physical and biological processes that together make up the temperature dependence of organic matter decomposition (Kirschbaum, 2006) and there are also several feedbacks that could partly cancel other effects (Davidson and Janssens, 2006). Because of the complexity and variety of situations, sustainability of current cropping systems is strictly related to specific contexts.

Current practices of rainfed farming systems on hilly lands of Central Italy rely on winter cereals such as durum wheat and industrial crops as sunflower and sugarbeet. Such rotations are implemented making the recurrent extensive use of summer deep plowing and hence long bare-soil intercropping periods between winter cereals and summer crops. Low soil organic matter content is one of the most important concerns emerging from the interaction between these cropping systems and local ecological constraints (Roggero and Toderi, 2002a; 2002b).

The mix of socio-economic and climatic factors driving changes in the specific context of Italian extensive hill farming systems, recalls the need for reliable scientific tools to assess the medium and long-term impact of climatic changes on cropping systems to support more adaptive and sustainable systems (Potter *et al*. 2004). *Equilibrium* and *transient* climatic scenarios can provide the basis for the impact assessment. *Equilibrium* scenarios are created by generating a time series (e.g. 50-100 years) of daily weather data assuming constant climate, hence no time trend and constant CO_2 concentration. *Transient* scenarios are created by generating a time series of weather data resulting from changing climate related to the rate of increase of atmospheric CO_2 concentration. The expected impacts of *equilibrium* scenarios on crop performances are often assessed by averaging climatic and crop variables over a generated multi-year series with constant climate (e.g. Donatelli *et al*., 2002; Thomson *et al*., 2006). The long term impact of climatic change on soil fertility dynamics may be assessed on the basis of *transient* climatic scenarios, which take into account the mixture of the long term interactions between climate and atmospheric CO_2 trends and the on-going adjustment of bio-physical processes.

The CropSyst simulation model (Stöckle *et al*., 2003) was specifically designed for multi-year sequential simulations of cropping systems and was successfully evaluated for field crops in several Mediterranean environments (e.g. Pala *et al*., 1996), including Central Italy, under both current and climate change conditions (Donatelli *et al*., 1997; Tubiello *et al*., 2000).

The objectives of this paper are:

- To present climatic change impact assessment on crop yield, water balance, and soil organic matter dynamics in the context of one of the most widespread cropping systems of Central Italy;
- Discuss the implications for developing adaptation strategies for the long term sustainability of these cropping systems, and address further research.

Materials and methods

Experimental site and field data collection

The study is based on a systematic survey made since 1997 in the arable hill-lands of the Marche Region, in a site that was interested by the compulsory application of the EU agro-environment scheme over an area of over 2000 ha for five years (1996-2001; reg. EEC 2078/92).

Climatic and cropping system data were collected in 2000-03 from all fields of two micro-catchments (Spescia, 80 ha in size; 43° 33' N; 13° 04' E; and Bottiglie, 60 ha in size; 43° 31' N; 13°02'E), through field surveys and farmer's interviews. Details of the soil and climate characteristics of the site were described by Roggero and Toderi (2002a; 2002b), De Sanctis *et al*. (2006) and Corti *et al*. (2006). The soil type was characterised by high clay and calcium content, almost free of gravel, with a

Tab. 1 – Main soil characteristics of the Ap soil layers used for the CropSyst simulations. The characteristics of the other layers can be found on Corti *et al.* (2006). Values in brackets indicate the standard error.
Tab. 1 – *Principali caratteristiche degli orizzonti di suolo Ap usati per le simulazioni di CropSyst. Le caratteristiche degli altri orizzonti sono illustrate in Corti* et al*. (2006). I valori tra parentesi indicano l'errore standard.*

soil type1 / ***variable***	***b-VHFL***	***b-THC***	***b-UHFL***	***b-UHC***	***s-THFL***	***s-TUFL***	***s-VHFL***	***s-THC***
Layer depth (cm)	50	57	37	30	52	69	55	48
Sand g/kg	24 (1)	16 (1)	28 (1)	28 (1)	37 (2)	38 (1)	38 (1)	12 (0)
Silt g/kg	41 (1)	44 (1)	37 (0)	37 (0)	40 (1)	34 (1)	32 (2)	46 (1)
Clay	35 (0)	40 (2)	35 (1)	33 (1)	23 (1)	28 (0)	30 (1)	42 (1)
Organic C %	0.52 (0.01)	0.81 (0.02)	0.71 (0.01)	0.67 (0.02)	0.55 (0.01)	0.52 (0.02)	0.79 (0.03)	0.68 (0.01)
Bulk density	1.12 (0.09)	1.20 (0.07)	1.23 (0.08)	1.25 (0.05)	1.31 (0.05)	1.52 (0.01)	1.28 (0.02)	1.40 (0.02)
Porosity	54.5 (0.04)	51.1 (0.03)	50.0 (0.02)	48.9 (0.02)	46.3 (0.05)	38.0 (0.03)	48.2 (0.03)	43.1 (0.03)
Field capacity* cm^3 cm^{-3}	0.356	0.390	0.345	0.335	0.282	0.276	0.305	0.387
Wilting point* cm^3 cm^{-3}	0.199	0.227	0.197	0.186	0.139	0.150	0.172	0.229
Ks* mm h^{-1}	6.7	2.7	3.0	3.1	6.4	1.6	3.2	1.4

*= derived from Saxton et al. (2006) Ks = saturated hydraulic conductivity. [1]b= Bottiglie catchment; s = Spescia catchment.
*= simulati con Saxton et al. (2006) Ks = conducibilità idrica alla saturazione. [1]b=Bacino Bottiglie; s= Bacino Spescia.
THC: *Typic Haplusteps, clayey, mixed, mesic*; VHFL: *Vertic Haplustepts, fine-loamy, mixed, mesic*; UHFL: *Udic Haplustepts, fine-loamy, mixed, mesic*; FHC: *Fragic Haplustepts, clayey, mixed, mesic*; UHC: *Udic Haplustepts, clayey, mixed, mesic*; THFL: *Haplustepts, fine-loamy, mixed, mesic*; TUFL: *Typic Ustorthents, fine-loamy, mixed, mesic*; UVHF: *Udertic Haplustepts, fine-loamy, mixed, mesic.*

relatively high water holding capacity but little organic carbon content (Table 1).
The cropping system was based on the sunflower-durum wheat crop rotation, which was one of the most frequent in the area under the EU CAP. The following practices were monitored in all wheat and sunflower fields of the two micro-catchments, over three agrarian years (2000/01 – 2002/03): tillage time and method, fertilization time and rate, sowing date, weed management, harvest date, crop yields. These data were used to calibrate CropSyst.

Climate change scenarios
Fifty-years daily maximum and minimum temperature and daily rainfall dataset of two neighbouring weather stations was used for the simulation of future climatic scenarios.
The two locations (Osimo and Jesi) are approximately at the same altitude, same distance from the sea shore and about 20 km apart.
Two fifty-years *equilibrium* climate dataset (Table 2) based on Is-92a emission scenario (Donatelli *et al*., 2002; IPCC, 1995) were generated from a 20-years daily temperature and rainfall dataset (1979-98) from the weather station of Osimo (43° 29' N; 13° 30' E; 75 m a.s.l.). *Equilibrium* scenarios are characterized by steady conditions of [CO_2]: (i) "baseline", assuming [CO_2] = 350 ppm; (ii) 2040, assuming [CO_2] = 450 ppm. 2040 *equilibrium* scenario was characterised by an increase of the annual mean temperature of about +1°C, and by a significant increase of winter and spring rainfall.
Three 100-years climate datasets based on "baseline", "A2" and "B2" *transient* climate scenarios (Figure 1 and Figure 2) (IPCC, 2001) were generated by IBIMET-CNR, LaMMA (Barcaioli *et al*. 2004), from a 20-years (1981-2000) daily temperature and rainfall dataset of the weather station of Jesi (43° 31'N; 13°15'E; 96 m a.s.l.). *Transient* scenarios are characterized by an yearly increase of [CO_2] starting from current condition (350 ppm) reaching 840 ppm and 620 ppm on "A2" and "B2" scenarios respectively after 100 years. "Baseline" scenario is characterized by steady situation from current condition of [CO_2].
Transient climatic scenarios (2000-2100) did not show significant shift from "baseline" until 2040 (Figure 1). *Transient* climate change scenario "A2" was characterised by distinct temperature trend in the second half of the simulated 100-year series, particularly from year 70 onwards. In 2090The mean temperature of "A2" resulted higher than "B2" (+1.4°C in autumn-winter; +0.8°C in summer) and much higher (up to +2.7°C in summer) than "baseline".
The differences in seasonal and annual rainfall projections indicate a significant increase of summer-autumn rainfall for "A2" and a relatively steady rainfall regime for "B2" (Figure 2), for which a slight increase in spring

Tab. 2- Seasonal and annual mean values of temperature and precipitation of the different climatic scenarios under comparison. Expected shift in averages of transient scenarios in 2040 and 2090 have been estimated from second order polynomial re-gressions over the year range 2000-2098.

Tab. 2 *–Valori medi stagionali ed annuali di temperatura e precipitazione degli differenti scenari climatici utilizzati per le simulazioni. I cambiamenti medi attesi nel 2040 e 2090 sono stati stimati dalla regressione polinomiale di secondo grado su periodo 2000-2098.*

	Oct-Jan		**Feb-May**		**Jun-Sep**		**Annual**	
Scenario	**air temp avg. °C**	**Precip. cum. (mm)**	**air temp avg. °C**	**Precip. cum. (mm)**	**air temp avg. °C**	**Precip. cum. (mm)**	**air temp avg. °C**	**Precip. cum. (mm)**
Osimo equilibrium baseline (20 years mean)	**9.3**	**255**	**10.7**	**202**	**21.4**	**189**	**13.8**	**645**
Osimo equilibrium 2040	+0.8	+57	+1.1	+41	+1.2	+16	+1.0	+113
Jesi baseline (1952-2000)	**9.8**	**287**	**12.1**	**203**	**22.8**	**227**	**14.9**	**716**
Jesi transient A2 (in 2040)	+0.1	+6	+0.2	+14	+0.8	+11	+0.4	+33
Jesi transient A2 (in 2090)	+1.7	+50	+2.5	+74	+2.7	+12	+2.3	+137
Jesi transient B2 (in 2040)	-0.2	+11	+0.2	+30	+0.7	-7	+0.3	+37
Jesi transient B2 (in 2090)	+0.3	+15	+1.1	+34	+1.9	+3	+1.2	+53

rainfall was observed. The average annual rainfall of "B2" scenario was not significantly different from "baseline", while "A2" showed a significant increase of rainfall, particularly in summer and autumn.

Simulations

Using the soil profiles described in Table 1, eight multi-year simulations of the sunflower-durum wheat cropping system were run for each climate scenario described in Table 2. The field data observations (agricultural practices and crop yields) of all fields in the microcatchments over three years were used as a reference for the model calibration (Table 3 and Table 4).

The yield variation with time for each crop was estimated by calculating the coefficient of variation as the ratio between the square root of the error variance of the unbalanced one way ANOVA (between fields) and the pluriennal mean.

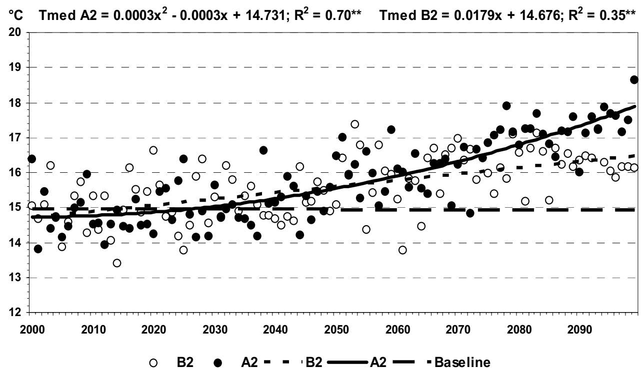

Fig. 1 – Dynamic of annual average air temperature following "A2" and "B2" transient scenarios.

Fig. 1 *– Dinamica della temperatura annuale media dell'aria secondo gli scenari transient "A2" e "B2".*

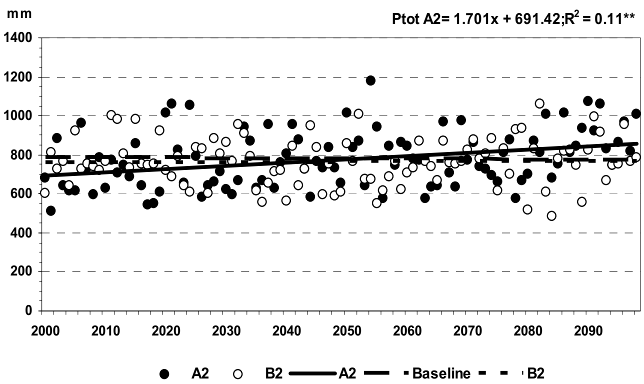

Fig. 2 – Dynamic of total annual precipitation following "A2" and "B2" transient scenarios (**=P<0,01).

Fig. 2 *– Dinamica delle precipitazioni annuali totali secondo gli scenari transient "A2" e "B2" (**=P<0,01).*

Tab. 3 – Main agronomic techniques used to calibrate CropSyst to simulate durum wheat and sunflower cropping system in Central Italy.
Tab. 3 *– Principali tecniche agronomiche utilizzate per la calibrazione di CropSyst al fine di simulare il sistema colturale frumento duro e girasole nel centro Italia.*

Agro-technique	*Durum wheat*	*Sunflower*
Plowing date	29 Sep	9 Aug
Harrowing and seed-bed preparation	6 Oct; 6 Nov; 10 Nov	1 Sep; 22 Mar
Fertilization (N units)	5 Nov (17); 15 Feb (26); 19 Mar (44)	21 Mar (28); 30 Apr (42)
Sowing	10 Nov	1 Apr

Tab. 4 – Field crop yields observed in the two microcatchments.
Tab. 4 *- Rese colturali osservate nei due microbacini.*

Crop	*Grain yield (t ha^{-1})*	*CV*
Sunflower	1.89	29%
Wheat	3.96	23%

Tab. 5 – Main crop parameters used to simulate sunflower and durum wheat with CropSyst.
Tab. 5 *– Principali parametri colturali utilizzati per simulare girasole e frumento duro con CropSyst.*

Parameter	*Durum wheat*	*Sunflower*
Optimal growing temperature(*) °C	10.0	10.0
Biomass/transpiration coeff.	4.1	5.2
Radiation/biomass conversion coeff.	2.3	3.0
Water Stress Index	1.0	0.5
Max root depth (m)	1.0	1.6
Evapotranspiration coeff.	1.15	1.1

(*) Threshold low temperature below which growth is limited.
(*) Valore temperatura soglia al di sotto del quale la crescita è limitata.

Tab. 6 - Sunflower: 25-years averages of grain yield (9% humidity) in a fifty-years sunflower-wheat durum rotation as simulated by CropSyst in relation to the different equilibrium scenarios under comparison.
Tab. 6 *– Girasole: medie di 25 anni di produzione di acheni (9% umidità) nel sistema colturale girasole – frumento duro simulate da CropSyst in relazione ai differenti scenari equilibrium presi in considerazione.*

Climatic scenario	*Mean grain yield (t ha^{-1})*	*coeff. of variation*
Baseline	1.91 b	23%
2040	2.13 a	16%

Means followed by the same letter are not significantly different ($P<0.05$)
Seguito dalla stessa lettera si intende non significativamente differente (P<0.05)

Crops yield and soil organic matter dynamics were simulated using the parameters described in Table 5. Durum wheat optimal growth rate temperature was set to 10 °C following the first set of simulations, in which durum wheat showed too high sensitivity to temperature increase. Biomass/radiation and biomass/transpiration coefficients were also calibrated.
The two 50-years weather datasets generated from *equilibrium* climatic scenarios of Osimo ("baseline" vs. 2040) were used to simulate grain yield and water balance. The three 100-years weather datasets generated from the *transient* climatic scenarios of Jesi ("baseline"; "A2"; "B2") were used to simulate the long term dynamic of soil organic matter in the 0-35 cm layer. All simulations were run considering the current agronomic practice.
Parameters used to calibrate soil organic matter mineralization, nitrification and denitrification were set to 0.4, 0.8 and 0.3 respectively (Table 5). These parameters were calibrated according to the expected annual mineral nitrogen naturally released (Francaviglia et. al 2000) and to the field observation of crop yield without nitrogen fertilization (Iezzi *et al*., 2002). The parameter for denitrification had no impact on nitrogen balance given that environmental conditions are such not to estimate any loss.
Cropping system simulations were performed on the crop rotation (25 years sunflower, 25 years wheat durum), using as an input the current agricultural practice observed in the fields of the two microcatchments (Table 3) and assessing the impact of climatic change in terms of grain yield and water balance.
The model was calibrated on the "baseline" climatic dataset of Osimo. The calibrated model was subsequently implemented on *equilibrium* and *transient* climatic change scenarios.

Results

Measured field data and "baseline" simulations

The observed field sunflower grain yield in 2000-2005, averaged over all micro-catchment fields (n= 3 to 8 depending on years) ranged between 0.65 and 2.68 t ha^{-1}, with a weighted mean of 1.89 t ha^{-1} and a coefficient of variation between years of 29%(Table 4).
The annual durum wheat grain yield, averaged over all micro-catchment fields (n= 5 to 11 depending on years) ranged between 3.05 and 4.31 t ha^{-1}, with a weighted mean of 3.96 t ha^{-1} and a coefficient of variation between years of 23%(Table 4).
"Baseline" simulations of sunflower grain yield, after calibration and averaged over the eight soil profiles, ranged between 0.62 and 2.62 t ha^{-1}, 1.91 on average and a coefficient of variation across years of 23%(Table 6). .
"Baseline" simulations of durum wheat grain yield, after calibration and averaged over the eight soil profiles, ranged between 2.47 and 4.53 t ha^{-1}, on average 3.64 t ha^{-1} and a coefficient of variation between years of 13% (Table 7). .

Tab. 7 - Durum wheat: 25-years averages of grain yield (12% humidity) in a fifty-years sunflower-durum wheat rotation as simulated by CropSyst in relation to the *equilibrium* scenarios under comparison.
Tab. *7 - frumento duro: medie di 25 anni di produzione di granella (12% umidità) nel sistema colturale girasole – frumento simulate da CropSyst in relazione ai differenti scenari equilibrium presi in considerazione.*

Climatic scenario	*Mean crop yield (t ha^{-1})*	*coeff. Of variation*
Baseline	3.64 a	13%
2040	3.68 a	20%

Means followed by the same letter are not significantly different (P<0.05).
Seguito dalla stessa lettera si intende non significativamente differente (P<0.05).

Tab. 8 – Water balance simulated by CropSyst in durum wheat and sunflower in relation to the different *equilibrium* scenarios.
Tab. 8 – Bilancio idrico simulato da CropSyst nel frumento duro e girasole in relazione ai differenti scenari equilibrium.

Durum wheat -*Frumento duro*

Climatic scenario	*Precipitation (mm)*	*ETo (mm)*	*Actual ET (mm)*	*Drainage water (mm)*	*WUE g H_2O/g DM*
Baseline	427a	585a	394a	100a	523a
2040	493b	503b	391a	194b	538a

"baseline": seeding on November 10, harvest on June 30 – July 22
2040: seeding on November 10, harvest on June 21 – July 13
Means followed by the same letter are not significantly different (P<0.05).
Eto=reference evapotranspiration
WUE= water use efficiency
DM= dry matter
"baseline": seminato il 10 novembre, raccolto tra il 30 giugno e il 22 luglio
2040: seminato il 10 novembre, raccolto tra il 21 giugno e il 13 luglio
Seguito dalla stessa lettera si intende non significativamente differente (P<0.05).
Eto=evapotraspirazione di riferimento
WUE= efficienza d'uso dell' acqua
DM= sostanza secca

Sunflower - *Girasole*

Climatic scenario	*Precipitation (mm)*	*ETo (mm)*	*Actual ET (mm)*	*Drainage water (mm)*	*WUE g H_2O/g DM*
Baseline	197a	572a	316a	10a	543a
2040	204a	541b	329a	14b	539a

"baseline": seeding on April 1; harvest on August 19 – August 29
2040:seeding on April 1; harvest on August 14 – August 25
Means followed by the same letter are not significantly different (P<0.05).
"baseline": seminato il 1 aprile, raccolto tra il 19 agosto e il 29 agosto
2040: seminato il 10 novembre, raccolto tra il 14 agosto e il 25 agosto
Seguito dalla stessa lettera si intende non significativamente differente (P<0.05).

Equilibrium climate change scenarios, crop yield and water balance

Sunflower mean grain yield slightly increased under 2040 *equilibrium* scenario and the coefficient of variation over time decreased (Table 6). However, most of these differences were caused by just one single very dry year in the "baseline" weather series, when simulated yield dropped down to 0.62 t ha^{-1}.

Tab. 9 - Water balance during fallow in relation to the different *equilibrium* scenarios.
Tab. 9 *– Bilancio idrico durante periodo intercalare con terreno nudo in relazione ai differenti scenari* equilibrium.

Fallow - *Terreno nudo*

Climatic scenario	*Precipitation (mm)*	*ETo (mm)*	*Actual ET (mm)*	*Drainage water (mm)*
Baseline	331a	367a	173a	48a
2040	408b	397b	186b	97b

"baseline" from June 30 – July 22 to April 1* and from August 14 – August 25 to November 10
2040 June 21 – July 13 to April 1* and from August 19 – August 29 to November 10
*next year
Means followed by the same letter are not significantly different (P<0.05)
"baseline" dal 30 giugno – 22 luglio al 1 aprile e dal 14 agosto – 25 agosto al 10 novembre*
2040 dal 21 giugno – 13 luglio al 1aprile e dal 19 agosto – 29 agosto al 10 novembre*
**anno successivo*
Seguito dalla stessa lettera si intende non significativamente differente (P<0.05).

The durum wheat mean yields and coefficient of variation simulated for 2040 *equilibrium* scenarios were not significantly different from "baseline" (Table 7).
Sunflower and durum wheat harvest were anticipated on average respectively by 4 and 10 days as a consequence of the higher temperature. Evapotranspiration was slightly reduced because of the differences in cycle length, while the new scenarios did not affected actual evapotranspiration of both crops. The changed climatic scenario also resulted in an increased average crop coefficient (Kc=ETc/ETo) of 10% and 15% during the crop phases of sunflower and durum wheat respectively, while average Kc did not change during the fallow phase. Water drainage increased under 2040 scenario as a consequence of the increased rainfall during early wheat growth and fallow (Table 8 and Table 9).

Transient scenarios and long term sustainability of current cropping systems

Under "baseline" *transient* scenario and starting from the current soil organic matter content of 0.9%, CropSyst simulated a progressive decrease of soil organic matter down to 0.63% after 100 years. Considering the 0-35 cm soil layer, an average loss between 0.17 and 0.28 t ha^{-1} year^{-1}of soil organic matter was estimated between year 2000 and 2040 under any climatic scenarios. Higher soil temperature simulated by CropSyst under future scenarios (Figure 3) seems to speed up soil organic matter min-

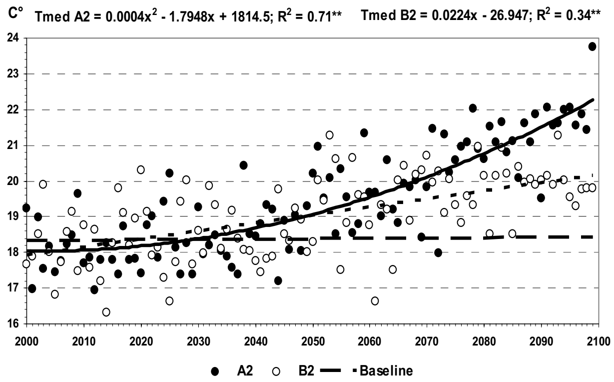

Fig. 3 - Dynamic of annual average soil temperature following "A2" and "B2" *transient* scenarios.
Fig 3 – *Dinamica della temperatura annuale media del suolo secondo gli scenari* transient *"A2" e "B2".*

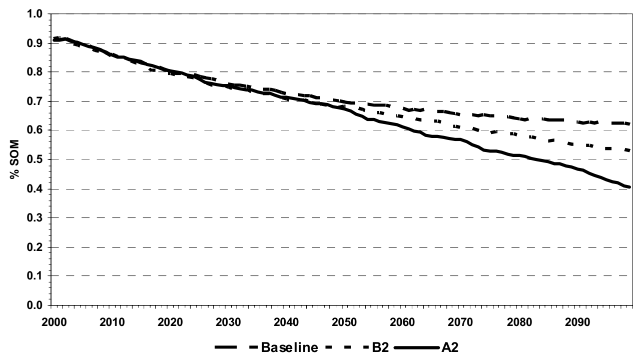

Fig. 4 - Soil carbon dynamic simulated by CropSyst as influenced by *transient* climatic scenarios.
Fig. 4 – *Dinamica del carbonio del suolo simulato da CropSyst secondo gli scenari* Transient.

eralization, in fact under "B2" and "A2" scenarios after 40 years, the soil organic matter decrease was sharper, leading respectively 0.53% and 0.42% after 100 years (Figure 4), corresponding to an average soil organic matter loss in the 2040-2100 interval of 0.08, 0.15 and 0.24 t ha^{-1} $year^{-1}$ under "baseline", "B2" and "A2" scenarios respectively. Moreover, whether the "baseline" and the "B2" scenarios seem to tend to an equilibrium, the response due to "A2" at the end of the simulation period still shows a steep decline.

Discussion and conclusive remarks

Crop yield estimations of CropSyst agreed adequately with experimental data in the specific environmental conditions of Central Italy. The simulation results on the sunflower-durum wheat cropping systems revealed no significant impacts of the *equilibrium* 2040 scenario on durum wheat grain yield and positive effects (+12%) on sunflower grain yield.

The wheat simulation results for 2040 scenario are consistent to what found by Amthor (2001) and were interpreted as the result of the compensatory effects of increased net assimilation due to elevated [CO_2] and the early crop development associated to higher temperatures that caused lower maximum LAI under 2040 scenario when compared to "baseline" (3,1 vs. 3,9).

Simulations also revealed unchanged hydrologic balance and water use efficiency of the sunflower-durum wheat rotation under 2040 climatic scenario, except for the increased drainage, which was directly related to a 20% increased autumn-spring rainfall. The simulated increased average Kc of the two crops under 2040 vs. "baseline" should be further investigated.

Results of the simulations on grain yield and water balance would suggest that current cropping systems are resilient enough to expected climatic changes in the incoming 3-4 decades. However, a relatively sharp decrease of soil organic matter content in the ploughed layer was simulated by the long-term simulations, even under "baseline" climate. These results were interpreted as an outcome of the current practice of leaving a long fallow period between durum wheat harvest and sunflower establishment and the insufficient soil cover in the autumn. Sharper rates of soil organic matter loss in the long term under "A2" and "B2" *transient* scenarios were well related to the forecasted soil temperature dynamics. Model outputs on soil organic matter dynamics represent a relevant basis for further investigations and should be interpreted in relative terms, until validation through field data is provided. However, simulation results clearly indicated that long term soil fertility of this cropping system, as known, is declining under current climatic conditions and would be further hampered under changed climate, particularly under "A2" scenario. The subtle yearly decrease rate of soil organic matter, and the relevant nutrient effects on crop yield may be temporarily concealed by higher fertilization inputs, could lead to a progressive decline of soil physical conditions in the long term, even under "baseline" climate. This should be regarded as particularly relevant in the context of the heavy clay soil texture of Central Italy arable hill-land.

The adoption of more conservative agronomic practices to minimise fallow periods and increase soil shading, targeted at improving soil organic matter balance (Hutchinson *et al*., 2007) should be further investigated in relation to their feasibility, efficacy and efficiency and to the economic and social implications that these changes would provide in the specific context of Central Italy. Simulation results suggest that particular attention should be paid for further bio-physical investigations on the influence of different agronomic practices on seasonal dynamics of mineralization of soil organic matter and its relationship with agronomic practices and soil temperature dynamics.

Acknowledgements

This study was funded by the Italian Ministry of Agricultural and Forestry Policies, finalised project "Climagri", subproject 2 Climate change and Agriculture, research Unit SAPROV - Dipartimento di Scienze Ambientali e delle Produzioni Vegetali, scientific responsible: P.P. Roggero. Alfonso Crisci (IBIMET-CNR, Laboratorio per la Meteorologia e la Modellistica Ambientale – LaMMA, Firenze, resp. G. Zipoli) provided the *transient* climatic scenarios that were used for the simulations. The research team coordinated by Giuseppe Corti (soil science, SAPROV) has provided detailed information on the soil profiles data that were used for the simulations. Gianni Bellocchi (Research Institute for Industrial Crops, Bologna) supported the calibration of CropSyst. The climatic data of Jesi were provided by the Italian Hydrographic Service of Bologna.

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