Changes in water resources availability for crop systems: a case study in the region of Umbria

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Abstract Water resources management must find a solution for competition among multi-users in agriculture. In particular, water for irrigation purposes, which has traditionally been the main factor to be satisfied, now competes with other strategic uses. Added to these socio-political changes are the climatic changes which influence both the water supply and demand, particularly for agriculture, which is greatly influenced by meteorological conditions (evapotranspiration, soil-crop-atmosphere water exchange, crop phenology). The aim of the paper is to discuss the potential effect of climatic changes on agricultural water requirements and on agricultural drought risk in the Region of Umbria, Italy. An analysis aimed at detecting the presence of trends in a set of meteorological, agrometeorological and drought indices was carried out in five different areas. Time trends for all variables were analysed using both parametric and nonparametric approaches. The results show that over the past 54 years the trends are higher in southeastern Umbria. In particular, significant upward time trends for the thermometric regime and downward trends for the rainfall regime were found. The irrigation requirements and the drought index show high upward trends at some locations where expected irrigation demand increments were estimated.

Key words agricultural drought index; climate change; crop water requirements

INTRODUCTION

Over the long-term, climate change, particularly global warming and precipitation dynamics, could affect agriculture in a number of ways (Olesen & Bindi, 2002), some of which would threaten crop water requirements. In the countries of the Mediterranean basin, irrigation is still today considered to be the activity with the greatest demand for water resources. Moreover, the signs observed of climate change lead one to suppose that water consumption for irrigation purposes is increasing because of the overall warming (Arnell, 1999). This thinking appears to be due to the meteorological approach adopted to analyse the problem. There are, in fact, relatively few studies on the effects of climatic trends on agricultural water consumption, and they are often based only on the analysis of long time series of climatic data (precipitation, temperature and their processing). Agricultural water use is instead highly influenced by the soil-plant-atmosphere water fluxes and consequently by the crop patterns too (Maracchi et al., 2005). In particular, the regulating function of the soil water zone and the specific plant's ability to modify its phenology can cause a "lamination" of the water shortage peaks and therefore a mitigation of the potential irrigation water requirement trends. This hypothesis is also supported by Moonen et al.

(2002) who concluded that despite a decrease in rainfall in Pisa (Tuscany, Italy), the number of soil moisture deficit days did not change in time and the drought risk does not increase. The above serves to emphasize that agricultural stress does not necessarily correspond to meteorological stresses, since the latter can affect uncultivated areas or can coincide with periods characterized by low crop water requirements. Moreover, the soil water content dynamics are also influenced by the characteristics of the specific crop. Thus the indices adopted for the quantification of the effects of climate change on agriculture might be calculated with reference to a single crop. These agrometeorological indices (Moonen *et al.*, 2002) might be capable of indicating the consequences of climate change for crop water requirements and production, and must be derived from both the classic climate parameters and the specific soil–crop–climate unit characteristics. In this paper, meteorological and agrometeorological parameters computed at different sites in the Region of Umbria (Central Italy) for specific crops were used to evaluate the climate trends and the agricultural impacts and adaptation to climate change.

MATERIALS AND METHODS

The Student and the Mann-Kendall tests were applied for parametric and nonparametric trend detection, respectively. The slope of the trend was estimated by both the Theil-Sen estimator (β) and the slope (b) of the linear regression.

Meteorological and agrometeorological parameters The set of meteorological parameters used in this study is given in Table 1. The meteorological parameters were derived from the time series of classic climate parameters (temperature and rainfall recorded at various meteorological stations in the Region of Umbria) and they enable the evaluation of the climatic change. In this area the April-August period is the average growing season (for many spring-summer crops); June-August is the average dry period (when irrigation is required) and September-March is the average wet period. In the wet period the recharge of the surface and subsurface water body takes place, determining the water resources availability, while the precipitation that occurred in the dry period affects the crop water requirements dynamic. In order to account for the impact of climatic changes on agricultural water requirements, a set of agrometeorological parameters were derived by processing the meteorological and crop data. The comparison between the results of the trend analysis of the meteorological and agrometeorological parameters will make it possible to evaluate the impact of the climate change both on the water availability and the water demand for agriculture in the Region of Umbria.

The agrometeorological parameters IR were estimated by the CropSyst model (Stockle & Nelson, 1996) using the recorded meteorological time series (daily maximum and minimum temperature and precipitation) and the soil and crop data as input. The daily reference evapotranspiration (ET0) values were estimated using the Hargreaves-Samani method. This method was validated for application in Umbria by a comparison with the Penman-Monteith equation. The crop growing seasons for the evaluation of the R_{cgs} , were computed yearly for each crop by CropSyst. On the basis of the runs theory applied to the daily soil water content simulated by the model,

Meteorological parameters	
annual rainfall	R_y (mm)
rain falling in the average growing season	R_{gs} (mm)
rain falling in the average dry period	R_d (mm)
rain falling in the average wet period	$R_w(\text{mm})$
mean amount of a rain event	h_m (mm)
mean rain event interarrival time	Δ_m (day)
mean minimum temperature in the average growing season	<i>Tmin</i> _{gs} (°C)
mean maximum temperature in the average growing season	<i>Tmax_{gs}</i> (°C)
mean minimum temperature in the average dry period	$Tmin_d$ (°C)
mean maximum temperature in the average dry period	$Tmax_d(^{\circ}C)$
date of last spring frost	LF (day)
Agrometeorological parameters	
sowing date	SD (day)
reference evapotranspiration in the average growing season	ETO_{gs} (mm)
reference evapotranspiration in the average dry period	ETO_d (mm)
rain falling during the single crop growing season	R_{cgs} (mm)
annual irrigation water requirement (irrigated crops)	IR (mm)
annual drought severity index in 40cm soil depth (rainfed crops)	SI (mm·day)

Table 1 Classification and abbreviations of the variables analysed for trend detection.

the *SI* was calculated for rainfed sorghum and sunflower with a truncation level corresponding to the crop critical point (FAO) with reference to the average soil water content in 40 cm depth of soil.

Cropsyst model simulation parameters For the nine irrigation districts of the Umbria region, the mean value of the soil classes in terms of available water content (AWC, uniform in the root zone) and the corresponding area percentage can be schematized as follows: class A, AWC = 8% (11% of the total area); class B, AWC = 10% (15% of the total area); class C, AWC = 12% (30% of the total area); class D, AWC = 14% (37% of the total area). The crops were selected according to the following criteria: (1) annual herbaceous crops (higher sensitivity to the seasonal climatic conditions than perennial crops) and in particular spring-summer crops; (2) two rainfed crops (sunflower, sorghum) and two irrigated crops (corn, tomato) in order to evaluate both the *IR* and the *SI*.

Meteorological stations The meteorological stations (Fig. 1) were preliminarily selected according to the following criteria: adequate length of the series; entirety and continuity of the series; optimal spatial distribution of the stations (Fig. 1) in order to allow a homogeneous coverage of the Umbria Region.

TREND ANALYSIS: RESULTS AND DISCUSSION

The results obtained by the Student's t and Mann-Kendall tests are consistent, although in some cases the significance level differs. The results are given in Table 2, together with the slope estimators: Theil-Sen (β) and the slope (b) of the linear regression. High (1%), medium (5%) and low (10%) statistical significance levels were used in this paper.



Station	Altitude	Temperature		Rainfall	
	(m a.s.l.)	period	Entirety (%)	period	Entirety (%)
Petrelle	293	1951-2004	88	1951-2004	92
Perugia	493	1916-2004	97	1924–2004	100
Spoleto	317	1951-2004	20	1951-2004	100
Orvieto	315	1951-2004	92	1951-2004	100
Terni	170	1951-2004	100	1951-2004	100

Fig. 1 Location of meteorological stations: temperature and rainfall series characteristics for the irrigation districts in Umbria.

Precipitation Significant decreasing trends in all the precipitation parameters were found in the southeastern part of the region (Terni and Spoleto). In Terni the significant decrease in the amount of rain falling within the time intervals considered can be explained by the high decreasing trend in the mean amount of a rain event, h_i , while the interarrival time, Δ_m , is stationary. In Spoleto the highly significant decrease in the annual rainfall, R_y , and the low or medium decrease in the rain falling in the other periods can be explained by both the decreasing trend in the h_i and the increasing interarrival time Δ_m . In Orvieto there is a downward trend only within the dry period. In the northwestern Umbria (Petrelle, Perugia), no changes were found in precipitation regimes. Only a low downward trend in the mean amount of a rain event (h_i) in

Meteorologi	ical para	Imeters			¢															
	Petrelle				Perugi	la			Orvieto				Spoleto	_			Terni			
	t	MK	q	β	t	MK	q	β	t	MK	þ	β	t	MK	þ	β	t	MK	q	β
R_y			-1.51	-0.56			-0.89	-0.58			-1.67	-2.87	 	 	-4.70	-5.90	 	 	-5.73	-6.10
R_{gs}			0.32	0.70			0.14	0.64			-0.19	-0.58		I	-1.11	-1.33	 	 	-1.61	-1.64
R_d			0.00	0.00			0.26	0.34		 	-0.62	-1.35		Ι	-0.93	-1.45	 	 	-1.33	-1.96
R_w			-1.83	-1.88			-1.04	-0.98			-1.48	-2.31	 	 	-3.60	-4.87	 	 	-4.10	-3.69
h_i	Ι	Ι	-0.02	-0.03			0.01	00.00			-0.01	0.00	Ι	I	-0.02	-0.02	 	 	-0.06	-0.04
\varDelta_m			0.00	0.00			0.00	0.00			0.01	0.00	‡	++	0.01	0.02			0.01	0.01
$Tmin_{gs}$			-0.01	-0.01	+ + +	+ + +	0.02	0.01			0.01	-0.01	+ + +	+ + +	0.04	0.05	+ + +	+ + +	0.03	0.03
$Tmax_{gs}$	Ι	 	-0.02	-0.03			0.01	0.00			0.00	-0.02	+ + +	+ + +	0.05	0.04	 		-0.02	-0.01
$Tmin_d$			0.00	-0.03	+ + +	+ + +	0.02	0.01	+		0.02	0.00	+ + +	+ + +	0.06	0.05	+ + +	+ + +	0.03	0.03
$Tmax_d$			-0.01	-0.01			0.01	0.00			0.06	0.05	‡ + +	+ + +	0.05	0.05	Ι		-0.02	-0.01
LF			-0.04	-0.33	 	 	-0.23	-0.30			0.03	0.21	Ι	Ι	-0.33	-0.43	 	 	-0.55	-0.63
ETO_{gs}			-0.63	-0.79			-0.01	-0.33			0.07	-0.58	+ + +	+ + +	1.23	0.92	 	 	-1.36	-0.77
ETO_d			-0.29	-0.41			-0.04	-0.31			0.10	-0.24	+++++	+++	0.97	0.79			-0.86	-0.58

Table 2 Mann-Kendall (MK) and Student's t (t) long-term trend test results; the Theil-Sen estimators (β) and the slope (b) of the linear regression. The + corresponds to

continued overleaf

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Agrometeorologic	al parame	ters																			
		Petrelle				Perugia				Orvieto	C		S	poleto				<u>rerni</u>			
crop	soil	t	MK	þ	β	t i	MK	q	β	t N	ЛК	þ	β t	V	ЛК	þ	β t		MK	þ	β
SD Sunflower				0.31	0.35			-0.17	-0.13		0	.22	9.18).26 –	-0.25			0.15	0.16
Corn				0.15	0.28	 		-0.29	-0.22		0-	.02	0.22 -			.43 –	-0.50		I	0.12 -	-0.05
Sorghum				0.14	0.30		I	-0.08	-0.03		0+	.15	0.36	Ι	-).23 –	-0.14			0.13	0.17
Tomato				0.05	0.13		I	-0.07	-0.06		0	.17	0.08	Ι).24 –	-0.16			0.14	0.07
R _{gs} Sunflower			'	-0.65	-0.74			0.14	0.16	Ι	-1	- 64	1.02		-	1.22 –	-1.25 -			3.73 -	-3.51
Corn				0.16	0.08		+	0.64	0.95		0-	H LL	0.41		- L		-0.64		I	1.08 -	-0.93
Sorghum			'	-0.49	0.12			0.40	0.65	 	1	.30	0.93		- L	- 66.(-0.63	' 		- 96.1	-2.69
Tomato				0.69	1.08			0.19	0.36	I	0	- 22.	1.35		1	1.31 -	-1.49 -			1.80 -	-1.87
IR Corn	A			0.33	-0.13		I	-0.17	-0.14		0	.34	0.06	+	+).85	0.49			0.02	0.00
	В			0.30	-0.09		I	-0.22	-0.18		0	.55	0.58	+++	+).85	0.44		I	0.09	0.14
	С			0.40	-0.04		I	-0.11	0.00		0	.58	0.14	+	-C +).85	0.12		I	0.13 -	-0.05
	D			0.38	0.00		I	-0.16	0.00		0	.43	0.00	++	C	.93	0.00			0.03	0.00
Tomato	Α			0.43	0.31		I	-0.19	-0.24		0	.29	0.04		- L).30 –	-0.01		I	0.34 -	-0.36
	В			0.58	0.37		I	-0.22	-0.01		0	.57	0.26		C).28 –	-0.25		I	0.19 -	-0.13
	С			0.61	0.35		I	-0.24	-0.12		0	.54	0.04		C).23 –	-0.23		I	0.18 -	-0.41
	D			0.66	0.75		I	-0.13	0.00		0	.60	0.02		C).13	0.12		I	0.24 -	-0.06
SI Sunflower	Α		I	-0.23	0.00		I	-1.04	-1.37	+	Э	.02	2.16		(1	2.02	1.45	+ + +	+++++	3.95	3.56
	В			0.28	-0.73		I	-0.71	-1.62	+	ξ	.82	2.67		(1	2.65	1.97	+++++++++++++++++++++++++++++++++++++++	+++++++++++++++++++++++++++++++++++++++	4.96	5.84
	С			0.60	0.57		I	-1.00	-0.81	++	+	.36	4.00		(*)	3.60	4.80	+	+++++++++++++++++++++++++++++++++++++++	7.12	8.52
	D			1.12	0.68		I	-0.86	-0.84	‡	+ 5	.92	3.87	+	4	t.80	5.56	+++++++++++++++++++++++++++++++++++++++	+++++	7.76	10.56
Sorghum	Α		ı	-0.80	-2.56		I	-1.08	-1.00	+	7	.65	1.68		1	1.34	3.02	+	+	2.75	3.61
	В		'	-0.39	-2.48		I	-0.92	0.00	+	ε	.56	1.88		(1	2.06	4.44	‡	+	3.72	5.28
	С			0.38	-2.15		I	-0.66	-0.58	++	+	.67	2.83		τN	2.10	3.81	+++++++++++++++++++++++++++++++++++++++	++++++	5.44	6.16
	D		I	-0.06	-3.26		I	-0.62	-0.34	‡	+	.11	3.60		τN	2.42	5.08	+++++++++++++++++++++++++++++++++++++++	+++++++++++++++++++++++++++++++++++++++	7.40	7.00

 Table 2 Continued from overleaf.

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Petrelle was found. In particular, with reference to the water availability, the decrease in precipitation amount expected over a 30-year time span was estimated in Terni at -171.9 mm for R_y (\approx -19% of the present mean) and at -123 mm for R_w (\approx -21% of the present mean) and in Spoleto at -141 mm for R_y (\approx -14% of the present mean) and -108 mm for R_w (\approx -17% of the present mean). In spite of these expected reductions in the water resources availability in the Terni area, the impact on the agricultural water use should be limited due to the small irrigation district (4200 ha) and the presence of a river (the Nera) with a very high minimum discharge and a stationary flow regime.

In Spoleto, the irrigation district is large (15 823 ha) and the water resources is withdrawn from the Clitunno River characterized by a stationary flow regime but a limited discharge. Hence in this case the risk (frequency) of a high impact imbalance (agricultural drought) between water demand and availability should reasonably increase. With reference to the dry period the decrease in precipitation amount expected over a 30-year time span was estimated at -40 mm (\approx -26% of the present mean) in Terni and at -28 mm (\approx -16% of the present mean) in Spoleto. The related impact on water requirements are quantified by the next agrometeorological parameters.

Temperature At the Orvieto station the thermometric regime is stationary in time, while the minimum night-time temperatures in Perugia, Spoleto and Terni in both the average growing season and the dry period show high upward trends. The maximum daytime temperature shows a strong increase in Spoleto and a stable or even decreasing tendency in Perugia and Terni. Therefore, there is a symmetric increasing trend in the temperature in Spoleto, while an asymmetric warming is detected in Perugia and Terni. The maximum temperature in the average growing season shows a downward trend only at the Petrelle. The observed upward trends in the mean thermometric regime led to an increase of the evaporation process and therefore to a reduction in the water resources availability. The effect of the thermometric regime on the crop water consumptions are quantified by the agrometeorological parameters.

Last frost date The general tendency observed is toward a moving ahead of the *LF*, with the exception of Orvieto; a significant decreasing trend was recorded in Spoleto, Perugia and Terni, respectively, with low, medium and high significance.

Evapotranspiration Increasing trends in ET0 were found at the Spoleto station, due to the increasing trends found in the thermometric parameters. In Terni, high negative trends were found for both $ET0_{gs}$ and $ET0_d$. This can be explained by the observed increasing night-time temperature (minimum temperature), when no evapotranspiration takes place, and decreasing maximum temperature that led to a lower evapotranspiration level. This asymmetric warming is typically characteristic of a climate influenced by increased cloudiness (Balling & Idso, 1990). The same observations can be made for the Perugia station, where a negative (not significant) ET0 tendency was detected. This behaviour of the ET0 stressed the importance of the need to calculate it using the minimum and maximum temperature as well as the mean temperature.

Sowing date The *SD* was simulated for the selected crops. The analysis results show decreasing trends in Perugia and Spoleto at medium and high significance levels for sunflower and corn and at a low significance level for sorghum and tomato in Spoleto.

Rain falling within the crop growing season Negative significant trends were obtained at the Terni, Orvieto and Spoleto stations. The R_{cgs} shows a high/medium significance trend in Terni for all crops and a medium significance trend in Orvieto for sorghum and tomato. This result was expected, due to the negative (medium and high) precipitation trend at Terni in the entire time interval considered and to the negative (medium) precipitation trend in the dry period at Orvieto. Furthermore the negative trends found in R_{cgs} seems to be strictly correlated with the corresponding tendency in *SD*: when there are downward trends in *SD* (early sowing) no trends in R_{cgs} are detected and *vice versa*. This can be explained by the shifting of the growing season toward a wetter period. A medium negative trend in R_{cgs} in Spoleto for tomato was also found.

Irrigation requirement The simulated *IR* shows trends only at Spoleto for corn in all the soil classes. This result was expected due to the highly positive trends found in ET0 and to the negative trends in precipitation (also the R_{cgs} for corn, shows negative tendencies even though not significant at the levels considered). The analysis showed the tendency toward an increase in the water demand for irrigated crops when an increasing trend in ET0 and decreasing trend in precipitation occur at the same time (i.e. Spoleto). The only decreasing trend in the R_d seems not to be effective for the occurrence of increasing trends in the IR (i.e. Orvieto). Moreover, for the Terni station a compensation effect between decreasing precipitation and decreasing evapotranspiration leads to a stationary IR. The expected increment in corn IR was estimated in the Spoleto irrigation district (Fig. 1). The b coefficients found for corn in Spoleto (Table 2) for each soil class were applied to the present crop pattern, where 1800 ha are grown with corn, in order to estimate the increment in corn seasonal IR expected over a 30-year time span. The expected increment was estimated at +477 660 m³, which in terms of water requirements per ha corresponds to an increment of $+265 \text{ m}^3$ ha⁻¹ (\approx +9% of the present mean corn *IR*). This upward trend and the contemporary downward trend detected in the pluviometric regime leads to the conclusion that the agricultural drought risk in the area of Spoleto is increasing.

Drought Severity index The simulated SI shows high positive trends in Terni for all soil types and crops. This result can be explained by the negative trends in the rainfall regime. The same observation can be considered valid for Orvieto, where medium/low positive trends have been found for all soil types and crops. Spoleto also has a positive tendency. The tendency toward an increase in the SI is observed when a decreasing tendency in precipitation occurs (i.e. Orvieto, Spoleto and Terni). The expected increments in sorghum and sunflower SI were estimated in the Orvieto and Terni districts over a 30-year time span. The expected increment was estimated as the percent of the present mean SI at $+13 \div 17\%$ and $+16 \div 19\%$ for sorghum and sunflower in Terni and at $+11 \div 12\%$ and $+10 \div 12\%$ for sorghum and sunflower in Orvieto. An overview of the results obtained for the agrometeorological parameters show that the simulated severity index (SI) is more sensitive to the precipitation regime, while the irrigation requirement (IR) seems to be more sensitive to the reference evapotranspiration regime. This behaviour is probably due to the relative magnitude of the variables involved in the processes analysed: for the irrigated crops the actual evapotranspiration amount is close to the ETO, while the dry period rainfall (R_d) is usually negligible compared to the IR. As a consequence, the IR is more sensitive to the ET0 trends. For the rainfed crops, instead, the actual evapotranspiration amount is lower than the ET0 and close to the R_d ; hence the SI is more sensitive to the R_d trends.

CONCLUSIONS

Significant decreasing climatic trends in all the precipitation parameters were found in the southeastern part of the region where there will be a significant impact in terms of reduction in the natural water supply during the dry period (R_d) when the water demand is also at its maximum level. In Spoleto and Terni these negative tendency and impacts also extend to the wet period during which the recharge of the surface and subsurface water body typically takes place. An increasing trend in the mean daily temperature was detected in the central and southeastern part of the Region of Umbria with a further impact on the water resources availability. Only when the increasing trend in the mean daily temperature corresponds to a symmetric warming, is an increasing trend in evapotranspiration (ET0) level is found. The opportunity to anticipate the seeding date (SD) due to the increasing temperature, leads to the modification of the crop phenological time intervals with a growing season shifted toward a wetter season and a positive impact on agriculture. In fact the negative trends in the rainfall cumulated during the actual crop growing season (R_{cgs}) are mitigated if compared with the corresponding trends in R_d . The impacts of the climatic trends on agriculture are also quantified by: (1) the simulated irrigation requirements (IR) that show an increasing trend where increasing trends in ET0 and decreasing trends in R_{cgs} occur at the same time; and (2) the drought severity index (SI) that shows positive trends when downward trends in R_d or R_{cgs} are present. The soil available water content does not show any significant effect on the trends analysis performed. On the basis of these considerations, a general tendency in the southeastern part of the region toward a decrease in the water availability and an increase in the water demand in order to preserve the standard production yield of the present crop patterns, is expected for both irrigated and rainfed crops. In the former, the water supply is needed to balance the irrigation requirement, in the latter to mitigate the increasing water stress that can lead to a partial or total yield reduction.

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