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Evaluating productive and economic impacts of climate change variability on the farm sector of an irrigated Mediterranean area

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Abstract

Climate changes in agriculture act on various climate variables (precipitation, temperature, etc..) at different times of crop cycles. Many physical and technical relationships have to be represented even when analyzing a limited aspect of farm management. This work employs the net evapotranspiration (ETn) estimated with the EPIC model, as a synthetic index of the physical factors that the farmer considers in decisions on irrigation. The probability distribution of ETn is inserted into a territorial model of DSP that represents farm choices in conditions of uncertainty about water availability and irrigation requirements of crops. Recent trends of ETn suggest that the probability distribution of this variable may appreciably change in the near future. Also, water availability may become more variable due to changed rainfall. These modifications amplify uncertainty of management and, consequently, costs incurred by the farm typologies of the study area, which in many cases suffer an appreciable drop in income.

Keywords: Discrete Stochastic Programming model, EPIC, climate change, Net Evapotranspiration, water availability, irrigation needs.

JEL Q54 - Climate; Global Warming.

1. INTRODUCTION

The effectiveness of the implementation of CC adaptation policies in agriculture depends on their capacity to raise the interest of farmers to co-finance the investments sought by the policies. This interest is more likely to be captured if the RDP measures are defined against perceived changes by because they are already happening and threatening farming profitability. Moreover, requires consideration of the agricultural effects of CC at the local scale that is relevant for farms and for the design of the PSR. Examining the effects of the CC at a time scale short-term and a regional scale is complex because it must consider the changes more atmospheric variables, at different times of the crop cycles or of the management of farms. This means that, eventually, even for assessing limited aspects of farm management, many physical, technical and economic aspects have to be considered, with several problems of integration between the models and approaches of the climatological research, agronomical and economic.

The analysis described in this paper addresses these problems. On the one hand, it uses the net evapotranspiration (ETN= Reference evapotranspiration ETo - rainfall) as a synthetic indicator of the many physical factors influencing the farmer's choices on irrigation. Then, it checks the existence of an ongoing change in the ETn conditions and estimates the possible effect on irrigation over a near future period, when farmers will be deciding whether to join the measures of the RDP. The production and economic effects of changes in ETn conditions are simulated with a regional model of Discrete Stochastic Programming (DSP), which reproduces the choices of farmers under uncertainty about water availability and irrigation requirements of crops in an area that represents the classic Mediterranean irrigation conditions.

The impact of climate variables on cropping systems and the links between ETn and irrigation requirements of crops are assessed by the process-based model Environmental Policy Integrated Climate model (EPIC) (Williams et al., 1989). EPIC has been successfully implemented to assess the impact of CC on agro-ecosystems at the national (Brown and Rosenberg, 1999; Priya and Shibasaki, 2001), regional (e.g. Easterling et al., 1993; Dhakhwa et al., 1997; Niu et al., 2009; Chavas et al., 2009) and global (Tan and Shibasaki, 2003; Liu et al., 2007) scales. The Discrete Stochastic Programming (DSP) model (McCarl and Spreen, 1997; Preckel 2008; Connor et al., 2009) is able to represent the economic impacts of various uncertainties related to agriculture, like irrigation water availability (Calatrava and Garrido, 2005), productive results of technologies (Coulibaly et al., 2011), weather risk (Mosnier et al 2011), changes in management variables as driven by changes in climate variability (Dono and Mazzapicchio, 2010).

This study is characterized by adopting the short-run perspective of CCV instead of the long run side of climate change, and integrates the agronomic and economic analyses, by combining EPIC outputs with DSP simulations. It focuses on the probability distribution of ETn and of water accumulation in a dam used for irrigation, as respectively driven by short run modification of temperature, atmospheric CO2 concentration, and rainfall regime.

Our aim was to make an integrated assessment of the impact of CCV on farming systems at a high spatial resolution in the context of a Mediterranean irrigated district, able to represent the impact of short-term variations of biophysical and management variables, in order to support the implementation of adaptation policies. Despite the catchment case study scale of analysis, the implications of the results of our analysis can be generalized to support regional policy schemes which would benefit of a sound assessment of key variables uncertainty at various times during the crop year. The results are discussed to identify the elements of vulnerability of the most diffuse farm types to CCV, an issue which is becoming a priority of the European research agenda on adaptation measures to CC for the next RDP (Orlandini et al., 2008; Reidsma et al., 2010).

2. MATERIALS AND METHODS

2.1. Case study area

The study area is located in NW Sardinia, in an homogeneous climatic zone of the central Mediterranean basin (Brunetti et al., 2002, Brunetti et al., 2004) which during the 1950-2002 period experienced a remarkable negative precipitation trend and a temperature and evapotranspiration increase; future climate scenarios show that such trends will be further exacerbated in the 2040-2070 time frame (García-Ruiz et al., 2011).

The study focuses on the Cuga hydrographical watershed (40.61°N; 8.45°E; 350 km2). In a portion of this area the Nurra Water User Association (WUA - Consorzio di Bonifica e Irrigazione della Nurra) supplies irrigation water from the 84Mm3 of the Cuga lake. Over the past 15 years, irrigation water was provided to some 2,900 farms scattered in an area of about 40 km2. Since 2001 the WUA charged water costs on the basis of the actual water consumption. Most of the farms have also access to additional groundwater from private wells. The Cuga dam water system also serves the local municipalities with drinking water (~40% of the total supply). In years of water scarcity, such as it happened in 1995, 2000 and 2002, priority was given to domestic consumption and agricultural water was restricted.

2.2. Farm management and climate uncertainty in the case study area

The predominantly autumn-winter rain is unreliable, and this has a major effect on the quantity of irrigation water stored in reservoirs managed by the WUA. The seasonal amount of irrigation water required is closely related to the evapotranspirational demand. The autumnal planning of farm activities is constrained by the uncertainty conditions on the amount of water in the reservoir, and on the summer crops' yields and irrigation water requirements. This latter aspect is still uncertain in April when, instead, the condition of water accumulation in the reservoir has occurred and is known by farmers. The change in variability of autumn-winter rainfall and of summer temperatures modifies the uncertainty on irrigation requirement of crops and on water availability in the reservoir. An increased uncertainty makes the planning of the cultivation activities more complex and increases the cost of possible mistakes.

2.3. Model input datasets

The uncertainty and its modifications were estimated with EPIC, @Risk and DSP model simulations, using four datasets: (i) the weather dataset including daily rainfall, min and max temperature, that were used as descriptors of the prevailing climatic conditions; (ii) the dataset provided by the Nurra WUA on the accumulation levels in the reservoir for the single months of a selected period; (iii) the dataset reporting the structure of agricultural farms, prices of products and inputs and cropping techniques adopted in the area in 2004; (iv) the cropping systems dataset, that was built from local farmers’ structured interviews and literature data (Dono et al., 2008).

The weather dataset was composed of a continuous series of daily observations covering 1951-2009, recorded at the weather station of Alghero airport (40°38′N 8°17′E, 23m a.s.l.). This dataset, integrated by the corresponding values of atmospheric CO2 concentration as obtained from NOAA (2010), was used to simulate the annual and monthly levels of ETn, and of irrigation requirements, and yield for major irrigate crops in the area. These simulations were conducted for the same years of which were available meteorological data and in the climatic scenario of the near future. The same weather dataset was also used to estimate the water accumulation levels in the reservoir, based on data provided by the Nurra WUA.

The regional DSP model is based on blocks of different representative farms whose structural aspects (size, specialization and availability of groundwater) were built from data provided by the Farm Accountancy Data Network, the WUA, the 2001 Census on Agriculture, and by field surveys conducted for the MONIDRI/RIADE research project (Dono et al., 2008). Field surveys were also used made to get information on the agricultural practices in the area (Dono and Mazzapicchio, 2010).

The soil dataset was built from representative soil profiles of irrigated fields of the study area (Madrau et al., 1981) and evapotranspiration was estimated using the Hargreaves equation on the basis of daily rainfall and temperature data (Hargreaves and Samani, 1982).

2.4. The estimate of ETN with the EPIC model

Many irrigated crops are practiced in the study area. Adequate assessments on the effects of climatic conditions on their irrigation were available only for maize and alfalfa, while for the vast majority of those crops no similar estimate was available. This prevented from estimating the probability distributions of their water requirements as done in analogous studies that focused on modifications of those functions as sign of CCV (Dono et al., 2011). These limitations were overcome by using the net evapotranspiration (ETN) as a synthetic index of physical factors considered by farmers in managing irrigation, and by detecting the changes of the probability distribution of the ETN as result of the CCV.

The monthly ETN was estimated with the Environmental Policy Integrated Climate (EPIC) model by valuing the potential evapotranspiration (ETP) and subtracting the volume of rainfall in the area. These estimates were obtained with EPIC on the basis of the following two weather datasets: (i) baseline, obtained from the observed daily maximum and minimum temperature and rainfall and actual atmospheric CO2 concentration in 1951-2010; (ii) near future, obtained from a 60-years daily weather dataset generated by WXGEN (Hayhoe, 1998) from the 2001-2010 subset of observations.

The following parameters were used to generate the near future climate dataset with WXGEN: relative frequency of wet and dry days; rainfall (monthly mean, standard deviation and skewness); air temperature (monthly means and standard deviation of daily maximum and minimum values) and solar radiation. The CO2 concentration for the near future scenario was set as the observed average in the 2000-2009 decade (NOAA, 2010).

The same dataset and approach was used to estimate with EPIC monthly water requirements, crop yield and WUE of grain and silage maize, and of alfalfa cultivated with low and high water. In this regard the EPIC automatic irrigation option was set to minimize water stress during the growing season. Irrigation was automatically triggered when the soil water content was lower than 50% of available water in the root zone. Irrigation events were limited to no more than one every four days. The EPIC crop parameters DLAP11, HMX2 and PPLP23 were calibrated on the basis of the crop yield dataset obtained from the farmers' interviews to check if the simulations were accurate enough for reliably representing the actual results for maize grain and silage (table 1).

Table 1 – EPIC parameters that were calibrated with the observed yield dataset.

Parameter	Default value	Calibrated value
DLAP1	15.05	10.10
HMX	-	3.1
PPLP2	7.77	6.77

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1. First of two points on a non-stressed plant's leaf area development curve, where the digits preceding the decimal point represent the fraction (%) of the growing season, and those following it the fraction of the maximum potential leaf area index.

2. Maximum crop height in metres.

3. Second of two points on plant population curve, where the number before the decimal point represents the number of plants per m^2, and the one after the decimal point the proportion of maximum leaf area achieved for that plants density.

2.5. Probability distributions of ETn

Given the EPIC output of ETn in April-October, when most of irrigation takes place in the area, probability distributions were estimated under baseline and near future climate. This was accomplished by means of the @Risk software that uses Maximum Likelihood Estimator (MLE) for estimating the function parameters and a $\chi 2$ test to identify the function that best fitted the dataset (www.palisade.com). Thirty probability distributions were estimated based on subsets of baseline 30-years data (progressing year by year from 1951-1980 to 1981-2010), assuming that a 30-years' time frame is the one farmers consider to construct their experience and hence their expectations on ETn and, hence, on general requirements irrigation water. The goodness of fit of each probability distribution vs. observed data was tested using a chi-square test.

Also the CCV was tested by comparing those probability distributions between them with a □2 test.

The probability distribution of the ETn based on the three decades preceding 2004 (1974-2003) was used as a control for the validation of the baseline version of the DSP model[4].

The entire 60-year EPIC output for ETn, corresponding to the near future climate, was used to estimate the probability distribution representing the expectation of farmers given the impact of current CCV. The assumption was that, if the probability distributions are shifting because of CCV, the estimate of the near future probability distribution would be best generated relying on the observed weather data from the most recent ten year period. This generates a probability distribution which is close to what the farmers will experience in the near future. This near future probability function was compared with the baseline using a χ 2 test, to check for significant differences[5].

Finally, the range of the probability distribution of ETn based on 1984-2003 weather data was divided into two states: (i) normal (P=0.75), which corresponds to the business as usual behavior and (ii) high (P=0.25), corresponding to ETn levels significantly higher than normal. Based on the EPIC outputs of ETn, each of the twenty years 1974-2003 was assigned to one of the two states and the mean values of the years falling in each state were considered as the representative values in the DSP model.

Likewise, the range of ETn values from the probability distribution of the near future state was divided into normal (P=0.75) and high (P=0.25) states. The ETn levels of the each of the sixty near future outcomes were assigned to the two states and averaged to obtain their representative values in the DSP model. These values represent the main indicators that we assumed farmers would have considered to choose whether to join or not the adaptation measure subsidies under near future conditions.

2.5.1. The relationship between ETN and irrigation requirements in the DSP model

After defining the two states of ETn and their representative values, the relationship between this parameter and the irrigation requirements of crops grown in the area was established. For this purpose crops were divided into two groups.

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[4] The choice of year 2004 was made because a complete set of the aerial photographs of the area in that year was available to validate the DSP model ability to reproduce the agricultural land use in the catchment.

[5] A chi-square test was performed to check the influence of the type of weather data input on the probability distribution of maize irrigation requirements based on EPIC simulations. The null hypothesis was accepted when comparing the probability distributions using actual observed weather data (1984-2003) or the weather data generated by WXGEN on the basis of the same 20 years of 1984-2003 observation.

The first includes the cultivation of corn and alfalfa for which weather data can be inserted into EPIC to simulate the entire production process and estimate yields, irrigation requirements and WUE. The mean values of these parameters for the years assigned to the two states of normal and high ETn, were included in the DSP model as representative of the results of those crops in these conditions.

The second group includes crops (vegetables and fruit) whose production cycle is not reproduced in EPIC. Irrigation volumes of these crop in the two states of ETn were estimated by considering that farmers always carry the soil to field capacity and fully make up the loss of moisture due to the ETN. The mean irrigation volume, as detected by interviewing farmers and technicians in the area, was hence multiplied to the percentage differences between the mean of ETN, and its value in the two states. Impacts on yield were neglected because the fruit products are less influenced by atmospheric concentration of CO2, such as C3 and C4 crops of the other group.

2.6. States of water availability in the dam

Dono and Mazzapicchio (2010) examined the changes in the probability distribution of water accumulation in the Cuga reservoir. The probability function parameters were estimated on a 20-years dataset using MLE, by means of @Risk. The estimate was reiterated by progressively shifting the 20-years dataset from 1965-1984 to 1984-2003 and the differences between the corresponding probability distributions were analysed on the basis of the relevance assumed by three states of water accumulation derived by the management policies of the basin by the WUA: (i) low state, scarce water availability for agricultural use, water in the reservoir mainly allocated for drinking water; (ii) intermediate state, irrigation volumes limited by the WUA; (iii) abundant state, unrestricted volume of water available for irrigation. The levels and probabilities of those states of accumulation, as estimated in the 1984-2003 period, represented the 2004 expectations in the DSP model. The expectations under the near future state were obtained by projecting the trends of probabilities of the three states estimated since the sixties.

2.7. Agricultural production and climate uncertainty

Discrete Stochastic Programming (DSP) models describe a sequence of choices made in stages, under conditions of uncertainty related to byophisical or management variables (McCarl and Spreen, 1997; Preckel 2008). Calatrava and Garrido (2005) used DSP to model farmer's behaviour and water markets exchanges equilibrium under uncertain water supply. Coulibaly et al (2011) used DSP to represent the uncertainty related to the adoption of new cereal technology in the Malian cotton zone and the subsequent conditional strategies of farmers which allow future decisions to be influenced by past decisions. Mosnier et al. (2011) used a sequence of recursive DSP models to simulate successive stochastic weather events over a long period to be managed in a suckler cow herd, combined with grassland crop production. DSP models have represented the effects of change in a single climatic component (Dono and Mazzapicchio, 2010); Connor et al., (2009) applied a two-stage model to evaluate the variation of two climatic components.

The three-stage DSP model of this study represents the sequence of decision making under uncertainties at three moments during the year. The first stage represents decisions taken in September-October, on cropland allocated to the autumn-winter crop and that reserved for spring-summer crops: uncertainty is highest and includes the irrigation water requirements of crops (technical coefficients) and water availability in the dam (productive resource). The second stage occurs around April and coincides with the sowing of the spring-summer crop and the beginning of the irrigation season. Water availability in the dam is known but there is uncertainty about the irrigation requirements that will depend on actual spring-summer evapotranspiration. The final stage occurs in summer, when July-August temperatures determine actual irrigation water requirement and yields of crops. According to this approach, farmers are aware that their decisions under uncertainty may lead to sub-optimal results, hence adopt defensive behaviours against the consequence of non-optimal outcomes. In particular, calculate the expected income of optimal and sub-optimal results for each state of nature, and choose the one with the highest expected income. The inclusion of sub-optimal results generates an additional cost because the weighted income is lower than the optimal solution under condition of certainty. This cost may increase if CCV alters the states of nature or their relative probabilities (Dono and Mazzapicchio, 2010).

2.8. DSP model's mathematical structure

The DSP model of this study is formalized as follows:

$$(1) \quad \max_{\boldsymbol{x}_1, \boldsymbol{x}_{3_{\boldsymbol{k},\boldsymbol{r}}}} \boldsymbol{Z} = \boldsymbol{GI} * \boldsymbol{x}_1 + \boldsymbol{P_k} * \boldsymbol{P_r} * \boldsymbol{GI_r} * \boldsymbol{x}_{3_{\boldsymbol{k},\boldsymbol{r}}}$$

subject to

$$(2) \quad A * x_1 + A * x_{2_k} \le b_k \qquad \forall k$$

$$(3) \quad A * x_1 + A_r * x_{3_{k,r}} \le b_{k,r} \qquad \forall k, r$$

$$(4) \quad x_{3_{jsp,k,r}} = x_{2_{jsp,k,r}} \qquad \forall jsp, k, r$$

Z is total gross income; x1, x2 and x3 are vectors of cropping activities (expressed in hectares) influenced by the conditions obtained during, respectively, the first, second and third stages; Pk are the probabilities associated with the availability of reservoir water, and Pr those with the various irrigation requirements and yields; GI is the gross income of each activity; A is a matrix of technical coefficients; and b is the quantity of available resources. Constraint (2) refers to choices made at the first and second stages, and constraint (3) to choices made at third stage. These constraints include the probabilities of the possible states of nature and, therefore, results. Constraint (4) maintains the area of spring-summer crops (jsp) when moving from the second to the third stage. It affects the option to change the farm cropping systems when the expected state of nature used as reference their setup does not occur. If a farmer predicts a lack of water in the reservoir and extends the area of rain-fed winter crops, irrigated spring crops can be cultivated only in the remaining area, even if a state of abundant water availability occurs. The model considers three states of water availability and two states of ETn and, henceforth, of irrigation requirements, each associated to a probability value. This generates six combinations of events, each of them giving one optimal and five sub-optimal results: farmer is assumed to select the combination associated with the highest expected income.

The baseline of the model is built in two steps. First a version is developed that reflects the experience of farmers on biophysical and management variables and reproduces their choices in 2004. The results of this version is validated by comparing with the similarity index of Finger-Kreinin, its land use vs. the actual cultivation pattern obtained by the aerial photographs of the area in 2004. Then, the baseline version of the model is obtained by including the effects of the Fischler reform. The near future version embeds the effect of recent trends in CCV on the corresponding variables. The outcomes of the baseline and near future versions are compared for assessing the impact of the CCV induced changes in the use of resources and profitability under the near future condition, when farmers will have to choose among the adaptation measures to CC. Two other future scenarios were also considered: change in water accumulation included only alterations in the availability of water dam; change in ETn only modifies ETn and, henceforth, irrigation requirement of crops and yields of maize and alfalfa. Comparisons of these future scenarios with the baseline shows how the variations in the use of resources and income were attributable to either specific or combinations of CCV induced changes. These results were assumed to represent the adaptation options of the farming systems in the area, given that specific production techniques and structures, and without the support of specific adaptation measures.

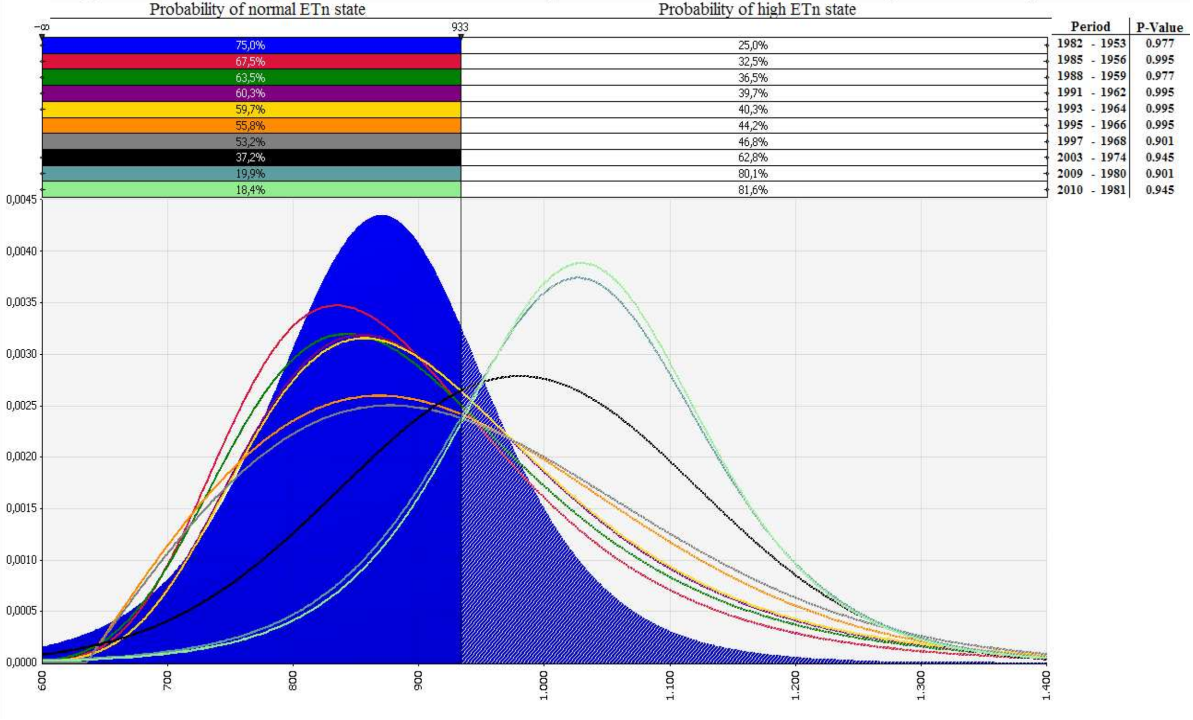
The versions of the model are solved using the General Algebraic Modelling System (Brooke et al., 1996).

3. RESULTS

3.1. CCV and irrigation requirements

The estimated probability distribution of ETn for the period April-October showed structural changes in the recent decades. The impact of CCV emerged by comparing the graph of the probability distributions from 1953-1982 to the subsequent sequences of 20 years up to 2010 (Figure 1).

Figure 1:probability levels for normal and high ETn states, selected periods, p-values for goodness of fit

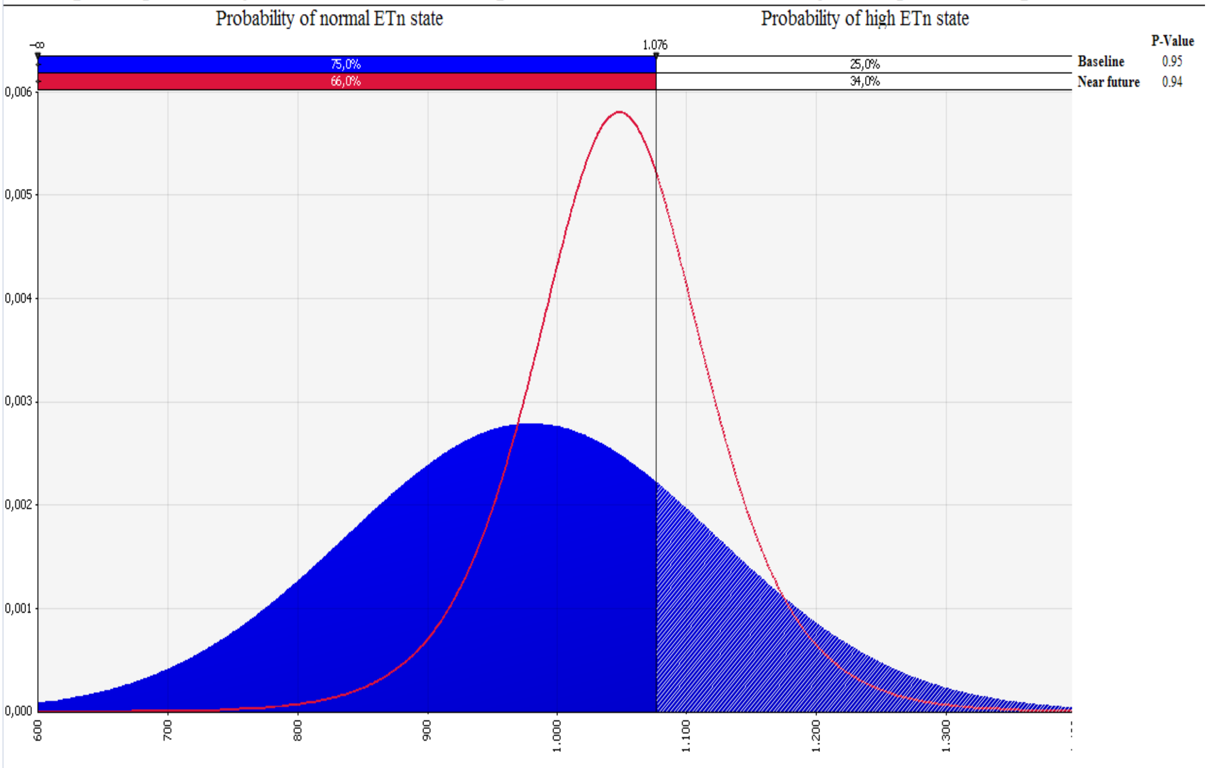


Probability of normal ETn state	Probability of high ETn state	Period	P-Value
75,0%	25,0%	1982 - 1953	0.977
67,5%	32,5%	1985 - 1956	0.995
63,5%	36,5%	1988 - 1959	0.977
60,3%	39,7%	1991 - 1962	0.995
59,7%	40,3%	1993 - 1964	0.995
55,8%	44,2%	1995 - 1966	0.995
53,2%	46,8%	1997 - 1968	0.901
37,2%	62,8%	2003 - 1974	0.945
19,9%	80,1%	2009 - 1980	0.901
18,4%	81,6%	2010 - 1981	0.945

The threshold which defined a high ETn with probability of 0.25 was set on the basis of the probability function built from 1953-1982 period, which corresponded to the period in which we observed the shift in CCV. The probability levels corresponding to this threshold were assessed using the probability distribution functions of the following 3-decade series. Moving from 1964-1993 to 1981-2010, the probability of high ETn progressively and significantly increased up to 0.403 in 1991-2010 0.816.

The shift of the distributions of ETn between the baseline period 1974-2003 and the near future, is highlighted by the increase in the probability of high state from 0.25 to 0.34 (Figure 2).

Figure 2:probability levels for normal and high ETn states, *baseline* and *near future*, p-values for goodness of fit



The p-values of the χ^2 associated to the goodness of fit of the estimated probability functions indicated an appreciable fitting (0.94).

Those changes corresponded to changed values of normal and high states of irrigation requirements under near future vs. baseline, and related yields input on the DSP model (Table 2).

Under baseline conditions, the total irrigation requirements for the high state of nature were substantially larger than under normal state respectively for both maize and alfalfa crops (Table 3). Yield slightly increased for grain and silage maize, and decreased for alfalfa crops, enough to generate a reduction of WUE when moving from normal to high states of water requirement, for both the maize and alfalfa crops (Table 2).

Under the near future scenario, total water requirements in the high state were also higher than in the normal state (Table 2). Yield changes under near future slightly increased for all considered crops, except for alfalfa dry that exhibited a reduction. However, those changes did not modify the reduction of WUE, when moving from normal to high states of irrigation requirements (Table 2).

In conclusion, even if with a different impact on WUE the generalized increase of irrigation requirements appeared to be the main effect of CCV, while the higher yield was substantially associated to the changes in CO2 atmospheric concentration.

Table 2: representative values and percentage changes for states of nature in irrigation requirements of maize and alfalfa

	Scenarios	Baseline		Near future	
		Normal	High	Normal	High
Silage maize	yield (ton/ha d.m.)	17.8	18.5	19.3	19.5
	total irrigation need (m^3/ha)	5,122	5,444	5,659	5,800
	WUE (kg d.m./mm)	34.7	34.0	34.1	33.5
Grain maize	yield (ton/ha d.m.)	12.0	12.1	12.8	13.1
	total irrigation need (m^3/ha)	6,811	7,163	7,602	7,776
	WUE (kg d.m./mm)	17.6	16.9	16.8	16.8
Alfalfa IRR	yield (ton/ha d.m.)	6.6	6.2	8.1	8.7
	total irrigation need (m^3/ha)	5,704	6,541	5,769	6,630
	WUE (kg d.m./mm)	11.6	9.4	14.1	13.1
Alfalfa DRY	yield (ton/ha d.m.)	6.1	4.9	5.2	4.6
	total irrigation need (m^3/ha)	1,987	2,063	1,768	1,970
	WUE (kg d.m./mm)	30.9	24.0	29.4	23.2

According to Dono and Mazzapicchio (2010), the probability distribution of water accumulation in the reservoir based on 1984-2003 was best fitted by a triangular function with a □2 value of 0.4 and a P-value of 0.94. Moving from the baseline to the near future scenario there was an increase in the probabilities of the low and abundant states of water accumulated in the reservoir at expenses of the intermediate state: this represented an increase in uncertainty about this variable moving towards the future (Table 3).

Table 3: water accumulation in the dam (000 m^3) and relative probabilities (%) in the study scenarios

States of Nature	Baseline		Near future	
	Water Accumulation	Probability	Water Accumulation	Probability
Low	9.153	***27.3***	4.968	***38.8***
Medium	28.691	***40.7***	29.276	***13.7***
High	36.787	***32.0***	42.053	***47.5***

Source: Dono and Mazzapicchio, 2010b

3.2. *Outputs of the DSP model*

The water availability data under the two states of nature, the corresponding EPIC outputs on irrigation requirement per decade and yields, along with the respective probabilities, were incorporated in the DSP model to generate the baseline scenario, which was validated against actual land use data for 2004. The resulting Finger-Kreinin similarity index of 94.2% was higher than that (91.1%) obtained by Dono and Mazzapicchio (2010), where the DSP model only considered the variability of water accumulation in the dam, and also higher than that (90.3%) observed from the LP model by Dono et al. (2008). This result confirms that the model was a good predictor of land use.

Shadow prices for irrigation water proved that it was likely to be a constraint particularly in April and June. The availability of external labour was never a limiting factor. The elimination of direct payments associated to the Fischler reforms resulted in a reduction of the area cultivated with cereals (primarily affecting durum wheat). Nevertheless, irrigation water continued to be a limiting factor not only in April, June and September, but also in May, July and August. Major constrains were expected in April and June, with shadow prices being three times higher than price of water applied by the WUA, while in May, July, August and September shadow prices were on average less than 5%. External labour was non-limiting throughout most of the year (the only exception being a ten day period in August), also considering the elimination of direct payments.

3.3. Changes in land use

The impact of Total CCV on the land use was a substantially stable total cropland area, which corresponded, however, to a relevant reduction of the irrigated cropland (Table 4).

Table 4: land use in the *baseline* and *near future* scenarios: hectares and percentage changes.

Scenarios	*Baseline*	*Near future: % changes over baseline*		
	Hectares	Total CCV	water accumulation	Etn irrigation
Cereal	1,718	24.3	24.2	9.5
Grain maize	*1,258*	*-9.2*	*-4.6*	*-2.6*
Silage maize	*382*	*-45.4*	*-39.9*	*-20.9*
Hay crops	*79*	*895.4*	*792.3*	*349.8*
Horticultural	1,175	-45.9	-27.9	1.2
Artichoke	*552*	*-83.6*	*-44.4*	*1.9*
Other vegetables	*602*	*-12.8*	*-13.7*	*0.5*
Other Forage crops	13,434	-1.0	-2.0	-2.0
irrigated	*723*	*-38.0*	*-33.0*	*-29.2*
Grasslands	2,998	0.2	0.1	0.2
Tree crops	2,677	0.0	0.0	0.0
Total Irrigated crops	5,391	-20.5	-14.4	-5.8
Total	22,003	-1.1	-0.8	-0.4

The largest relative negative impact was observed on silage maize; noticeable was also the reduction of some horticultural crops and of the area destined for irrigated forage (alfalfa and grassland). The two components of the change, water accumulation and ETn irrigation, had different impacts. In particular, in the ETn irrigation scenario, the reduction of cereals is smaller then in the other scenario and there is an even if slight increase of horticultural crops. The result of those changes is a smaller reduction of the irrigated crops when compared to the decrease generated by the other CCV driven modification.

3.4. Change in input use

Those changes modified the use of the most important inputs (Table 5). Under Total CCV the use of water provided by the WUA markedly decreased.

This was only due to the increased instability of water accumulation in the reservoir while the impact of the larger water requirements associated to the increase in ETn, augmented the use of water. In particular, the increase in ETn mainly raised the use of groundwater, which coupled with the increased instability of WUA supply generating a synergic effect of increase in the use of this resource.

Table 5: use of major inputs in the *baseline* and *future* scenarios. Absolute values and percentage changes in *near future* scenario against *baseline*.

Scenarios	*Baseline*	*Near future: % changes over baseline*		
	Absolute values	Total CCV	water accumulation	Etn irrigation
Total water (000 m^3)	21,942	-10.8	-11.7	2.0
From Consortium (000 m3)	19,004	-13.4	-13.6	1.7
From private wells (000 m3)	2,938	5.9	0.2	4.1
Total labour (000 hours)	2,020	-4.2	-3.0	0.1
Farm Labour (000 hours)	1,710	-5.0	-3.5	0.2
Non-farm Labour (000 hours)	311	0.2	0.0	-0.2
Nitrogen (tons)	1,031	-9.2	-5.6	-1.4
Phosphorus (tons)	2,129	-1.2	-2.1	-0.3
Potassium (tons)	2,003	2.3	0.8	0.5
Herbicides (tons)	4	-18.2	-11.8	-4.6
Insecticides (tons)	46	-1.6	-1.3	0.1
Animal feed (kg)	1,261	193.7	195.2	45.7

The total labour use was reduced because of the decrease in the use of farm labor. The use of chemicals was also reduced because of the change in water accumulation (P and K fertilizers and insecticides) and in irrigation requirements of maize and alfalfa (N fertilizers and herbicides). Finally, the purchase of external inputs such as feeds dramatically increased as a consequence of the higher unpredictability of reservoir water volume, which reduced the farm fodder production (Table 4).

3.5. Economic results

The economic analysis revealed that the Total CCV scenario would result in a small negative impact as percentage drop of agricultural gross margins (Table 6).

However, the negative impact increased when computed on net income calculated according to the fixed costs of the representative farms included in the model. The decrease was interpreted as caused by the increased variability in water accumulation in the reservoir, while the effect due to the change in water requirements due to increase in ETn was positive, even if negligible.

The reduction of gross income generated by the Total CCV was largely due to a decrease in crop sales, mainly of horticultural products and of grain maize (data not reported), which was not balanced by the general decrease of the variable costs. There was also an appreciable rise in spending for feed and for lifting of groundwater; this result occurred in both the simulation components, even if it was mainly due to the higher variability of water accumulation in the reservoir. Those changes also had implications on the net income, which varied when measured with or without payments of Common Agricultural Policy (CAP) which accounted for more than 26% of total net income and was stable and crucial in notably reducing the impact of the two CCV driven changes.

Table 6: economic results for the *baseline* and *near future* scenarios - absolute values (000 €) and percentage changes.

	Baseline	*Near future: % changes over baseline*		
Scenarios	*000 €*	Total CCV	water accumulation	ETn irrigation
Total revenue	65,214	-1.7	-1.4	0.2
Crop sales	*57,020*	*-1.9*	*-1.6*	*0.2*
Variable costs, *of which:*	18,566	-2.6	-0.9	0.3
technical means, of which:	*13,405*	*-5.3*	*-4.2*	*0.1*
herbicides/insecticides	*895*	*-8.2*	*-5.3*	*-0.1*
animal feed	*321*	*193.7*	*195.2*	*45.7*
extra-farm labor	*2,096*	*0.2*	*0.0*	*-0.2*
payments to the WUA	*510*	*-15.6*	*-16.1*	*2.5*
water pumping from farm wells	*87*	*7.6*	*0.6*	*5.0*
other	*2,147*	*-15.6*	*-7.1*	*-5.2*
Gross margin	46,649	-1.3	-1.5	0.2
Fixed costs	23,125	0.0	0.0	0.0
Net Income	23,524	-2.6	-3.0	0.3
Net Income + CAP	32,058	-1.9	-2.2	0.2

The described impacts were different among the single farm typologies included in the model to represent the productive heterogeneity of that specific territory (Table 7)6. This can be noticed by examining the percentage changes of net income inclusive of CAP payments (NI+CAP) in the near future scenarios over the baseline. It is also worth to consider the impact on the single farm typologies and on the groups of small, medium and large of those farms, clustered according to their NI+CAP values, with thresholds of € 24.000 and € 50.000.

Table 7: gross margin (GM), net income (NI) and NI inclusive of CAP payments per farm typology: absolute values (000 €) and percentage changes of NI + CAP payments.

Farm Typologies	number of represented farms	hectares per farm	baseline (000 €)			Total CCV
			GM	*NI*	*NI + CAP payments*	*Δ % over baseline*
large dairy cattle	*2*	*534.4*	*1,277*	*359*	*625*	*-28.8*
small - medium dairy cattle	*5*	*37.6*	*97*	*39*	*57*	*-20.1*
large mixed crops	*139*	*66.1*	*27*	*16*	*25*	*3.0*
medium mixed crops	*280*	*10.2*	*26*	*17*	*21*	*-1.0*
small mixed crops	*1509*	*0.7*	*4*	*3*	*3*	*0.7*
medium - large olive groves	*33*	*12.3*	*13*	*-9*	*40*	*-1.7*
small olive groves	*543*	*0.8*	*1*	*-1*	*4*	*-0.4*
medium - large horticultural	*41*	*14.8*	*27*	*20*	*25*	*-11.1*
small horticultural	*49*	*2.8*	*5*	*3*	*3*	*-49.0*
medium - large sheep	*34*	*64.1*	*49*	*24*	*30*	*-2.8*
small sheep	*94*	*26.1*	*20*	*10*	*13*	*-1.2*
large vineyards	*1*	*693*	*14,448*	*5,779*	*5,779*	*0.0*
small - medium vineyards	*136*	*2.7*	*44*	*26*	*26*	*-0.3*
Large farms	*8*	*243.7*	*2,186*	*837*	*914*	*-5.7*
Medium farms	*383*	*33.3*	*34*	*19*	*27*	*-0.7*
Small farms	*2475*	*2.8*	*7*	*4*	*6*	*-0.8*

3.6. Adaptation strategies

The simulated impact of CCV on the case study farming systems revealed three types of adaptation scenarios: (i) crop reallocation; (ii) farm extensification; (iii) changes in the use of external inputs. These results were the consequence of different adjustment paths followed by farms when not subsidised, with respect to the change in probability of biophysical and management variables. The major elements that characterize these various paths of spontaneous adjustment in the three groups of farms are reported in Table 8.

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1. [6] In this regard, note how different were some represented farms, with large vineyards and dairy farms whose cultivated land and income levels were much higher than other types. In contrast, the economic size of small farms, on average was really tiny. Also note that the CAP payments had a significant economic importance for small and medium-sized farms and in the case of olive groves generated an appreciable value of NI+CAP reversing the negative value of NI.

A reallocation behaviour emerged of crops/cropping systems among the types, with only mixed crops that increased their production of other vegetables (mainly melon and watermelon) primarily recurring to increased extractions of groundwater. Those changes in production patterns modified the value of sales and only mixed crops farms were capable to minimize the drop because of the increase of sales of vegetables. To this change of productive mix, an adjustment in resource use and associated costs was coupled. A general extensification trend emerged for small and medium farms, with the general reduction in the use of technical means and of farm labor. A significant exception was observed for water pumping from wells, and use of groundwater, that grew in both groups of farms because of the larger variability of the water provided by the WUA. Also related to this change was the rise of costs due to increase of purchased feeds, which was central in increasing production costs and worsening the economic balance in dairy farms of medium and large size, and in large sheep farms.

Table 8: percentage changes of land use (hectares) and budget components (000€) per group of farm typologies

Group of typologies	Dairy	Mixed crops	Olive groves	Horticultural	Sheep	Vineyards	Large	Medium	Small
Artichoke	-100.0	-78.7	-	-86.9	-	-	-100.0	-86.9	-80.2
Other Vegetables	-100.0	1.3	-100.0	-97.8	-27.3	-17.5	-100.0	-31.0	-7.5
Grain maize	-100.0	-0.3	-5.9	-41.8	-	-99.0	-99.5	-7.6	-10.6
Silage maize	-45.4	-	-	-	-	-	-45.4	-	-
NI + CAP payments	*-27.2*	*0.6*	*-0.9*	*-15.9*	*-1.9*	*-0.1*	*-5.7*	*-0.7*	*-0.8*
Crop sales	-22.8	-0.6	-4.1	-26.1	-7.9	-0.1	-0.2	-2.6	-2.7
technical means	-8.5	-2.8	-5.9	-31.8	-2.0	-0.6	-1.8	-4.7	-7.2
animal feed	386.7	-	-	-	28.8	-	386.7	25.0	-
extra-farm labor	7.8	0.8	0.0	4.0	-6.3	0.0	1.3	0.0	-2.2
water pumping from wells	-	9.3	14.3	5.4	1.8	-0.7	-0.7	8.9	5.2
Farm Labour (000 hours)	-27.2	0.6	-0.9	-15.9	-1.9	-0.1	*-1.2*	*-6.4*	*-4.5*

4. DISCUSSION

The change in the biophysical and management variables driven by CCV was rooted in the end of the seventies and was strengthened in the last decade. Hence, in the near future scenario, when farmers will be choosing among RDP measures for adaptation to CC, they may face a greater likelihood of major irrigation requirements and instability of the availability of irrigation water. Larger irrigation requirements were related to maximum temperature increases, while rises of atmospheric CO2 concentration may boost yield. This mixture of changes reduced WUE of maize and alfalfa in both states of normal and high irrigation requirements, which contributed to reducing the cultivated area of those crops, since the farm sector of the studied catchment was already operating in conditions of binding water availability.

The increased variability in the production of feed increased its purchases. This is consistent with findings of other studies on the response of livestock farms to changing climatic conditions (Mosnier et al., 2009, 2011). The greater variability in water availability provided by the WUA will also increase the use of underground source that the model assumed stable. This response is consistent with findings of Dono and Mazzapicchio (2010) and other studies that examined the irrigation decisions in contexts with different levels of uncertainty (Calatrava and Garrido, 2005).

The greater use of groundwater increases the environmental pressure of the farm sector. This increased pressure has also other components because the reduction in the use of chemical inputs, due to the decrease in the cultivation of maize, had only a local effect. Actually, the increase in purchases of feed rises the environmental pressure in areas where those products are cultivated.

The reallocation of crops/cropping systems among the different farm typologies does not indicate a process of specialization given the increase in cultivation of vegetables was observed only in mixed crop farms.

Among other things, the small farms loose their production of other horticultural crops, which reduces their sales, their net income, and their use of family labor. This will be generated on farms that already have a limited economic size.

5. CONCLUSIONS

The changed climate variability which is being observed under Mediterranean conditions can have relevant impacts on irrigated farming systems. The expected changes in rainfall, maximum temperature and atmospheric CO2 concentration are of relevance for the development of adaptation strategies also over a near future time frame. This may have profound implications for the formulation of agricultural policy aiming to support adaptation to CC.

This study identified the farm typologies to be targeted for supporting their adaptation to CCV in a near future time frame and relying on observed climatic data. This is crucial for designing effective responses at the policy level. In this context, water availability is strategic for Mediterranean agricultural districts because of its value in reducing the CCV vulnerability of cropping systems in the context of temperature rise. In particular, it implies that more effective and efficient surface water management would increase the adaptive capacity of the farm sector of the Mediterranean area under CCV. It also suggests that more emphasis should be given to improve the functionality of the collective infrastructures of water storage and distribution, and above all, the management of water resources by the WUA at the catchment scale. The environmental impacts of this investment can help to reduce the pressure on groundwater extraction, whose quality is significantly deteriorating in coastal areas. It may be therefore useful, among other measures, to set the RDP of EU programs to assist the WUAs in enabling management mechanisms of the reservoirs that, even beyond the catchment scale, allow compensating for the possible major alternations of meteoric influx and, therefore, of water availability. However, it is evident that the limited resources of the RDP cannot be sufficient to support the modernization of the collective structures of water delivery, and a plan is needed for modernizing these structures with specific funding.

It should not be neglected to support the reduction in the use of water resources that can be included as part of the cross compliance rules of Pillar 1. This intervention must relate to fruit and vegetable crops that are more typical of Mediterranean agriculture with programs based on Good Agricultural and Environmental conditions that promote a reduction in water demand for horticultural crops. However, this requires a reform of Pillar 1, which amends the audience of farmers interested in it, in fact, many fruit and vegetable farms are now strangers to such payments and, therefore, also to the constraints.

Specific attention should also be paid to the dairy cattle industry if this has to continue to be maintained productive under Mediterranean conditions. Indeed, the notable water requirement of maize cultivations exposes this sector to instability of the water sources, and to increase in irrigation requirements of most intensive forage crops. It is hence important to sustain the research of alternative solutions which may relate to alternative forage crops which are more drought resistant, and/or requiring less water, which may result in less intensive and external input dependent dairy farming systems for Mediterranean areas. The implications for such changes are worth of further research efforts.

Further research effort must also be devoted to improve the capability of such cross-disciplinary analysis, seeking for agricultural responses to medium-term changes in climate variability. For instance, the modelling exercise presented in this paper ignored any possible effects of CCV on pest and pathogen that, if increased due to CCV, would further increase costs for control measures. The impact of CCV on other aspects of agricultural production, such as the workability of the soil and the living conditions of livestock, may also be worth to consider.

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