Economic modelling of climate change scenarios and adaptation of Mediterranean agriculture

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Summary

This paper discusses some of the most relevant economic findings of two research projects, Agroscenari (www.Agroscenari.it) and MACSUR (www.MACSUR.eu), which analyze the impact of climate change (CC) on production levels and profitability of Italian and European agriculture for defining effective adaptation actions. Both projects provide research lines on climatology, agronomy, animal breeding and economics for building integrated models that simulate farmers' decision making in the context of CC. The integration sought in these projects aims at determining how climate variability (CV) normally influences production and management of farms, then, at assessing the impact of CC based on the change of this variability (CCV). The influence of CV on crop production and livestock farming is considered in this study. The relationships among CV, agricultural and livestock production are expressed by means of Probability Distribution Functions (PDFs) estimated for the main agricultural variables in both climate scenarios, present (Ps) and future (Fs). These PDFs, appropriately discretized, are then used to represent the expectations on productive variability in an economic Discrete Stochastic Programming model that simulates farm management decision making process under Ps and Fs. Comparing the model results in the two scenarios indicates the effects of CCV, given the possibility to adapt the use of resources and the cultivation techniques. These possibilities of adjustment are modelled based on the current technologies, production structures and markets. So, even if Fs is not far away in time, they may appreciably increase during the transition period. For this reason, the comparison of the economic results achievable in Ps and Fs is not intended to provide an estimate of the final economic impact, but to indicate the farm types and cropping systems that will suffer the greatest stresses from CC.

Key words: stochastic programming; climate variability changes; sustainability

JEL Classification codes: C61, Q12, Q54

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1. INTRODUCTION

A significant inter-annual variability has always been found in the sub-areas of a climatic zone when its meteorological conditions were analysed on decadal base , also in periods when climate was perceived as stable. This variability is generated by the combination of different mechanisms, whose action is synergistically influenced by global warming. In recent decades this latter component has increased its influence, leading to CCV. The following pages present an integrated study primarily assessing the effects of CV on crop and livestock production, and on farm management, of a Mediterranean agricultural area in the present. Then the impact of CCV on these aspects is assessed in the future (Dono et al., *forthcoming*).

The inherent variability of the Mediterranean climate is mentioned and explained by many studies highlighting the determinants and expressions of climatic variables in the different sections of this region (Navarra and Tubiana, 2013). It was shown that the atmospheric circulation in the Atlantic Ocean determines the variability of rainfall in the autumn period (Delitala et al, 2000; Altava-Ortiz et al, 2011). Similarly, it was shown that heat waves are a frequent feature of the Mediterranean summer (Colacino and Conte, 1995; Giles and Balafoutis, 1990; Matzarakis and Mayer, 1997; Karakostas and Gawith, 1994; Metaxas and Kallos, 1980; Prezerakos, 1978, 1989, Gaetani & Pasqui 2012, Gaetani et al 2012.), and several anomalous warm summers have occurred in the Mediterranean and in southern Europe over the last 60 years, with waves of different intensity and duration (Baldi et al., 2006; Segnalini et al., 2011).

The influence of CV on livestock and crop production is also extensively treated in the scientific literature. Many researches made use of specific mathematical and statistical models to investigate the relationships with livestock production (Johnson, 1987; Hahn, 1999; Vitali et al, 2009; Bertocchi et al, 2014; Bernabucci et al, 2014). Other analysis relied on models providing a rich characterization of optimal growth conditions and assessed the response of crops production under different climatic conditions (Brown et al, 2000; Liu and Tao, 2013; Dono et al, 2013). In various studies these models are used to assess the impact of CC by comparing crop yield or the requirement of inputs under conditions of current and future climate (Eckertsen et al., 2001; Semenov and Shewry, 2011; Rötter et al., 2012; Porter et al., 2013; Olesen et al., 2011; Palosuo et al., 2011; Reidsma et al., 2010; Iglesias et al., 2009).

The relationship between CV and agricultural activity can be included in mathematical models simulating economic choices of farmers in a context of uncertainty. One of those model tipologies, Discrete Stochastic Programming (DSP) (Hardaker et al., 2004), was used to represent the economic impact of many agricultural uncertainties: availability of irrigation water (Calatrava and Garrido, 2005a, 2005b), productive results of technologies (Coulibaly et al., 2011), weather risks (Mosnier et al., 2009), CCV (Dono and Mazzapicchio, 2010). Dono et al. (2013) assessed the impact of CC with a three-stage DSP model in which uncertainty regards water needs of crops and availability of irrigation water. They compared the results of the model executed with the PDFs of those variables under Ps and Fs: current PDFs were estimated on climate data of the last three decades, future PDFs were estimated by extrapolating data from climate observations of the last decade.

In this paper we propose a significant step-forward in knowledge to what was previously proposed in analysing CC impacts on agricultural systems (Dono et al 2013). Advancements concern in particular (i) the way climate scenarios were generated; (ii) the choice of combining climate, crop, livestock and economic modelling to improve the understanding on how CC could generate winners and losers among the different farming systems located in the same district and ultimately could result into changes in the agricultural land use and/or management. Present (2000-2010) and future (2020-2030) climate scenarios were produced through an approach known as Regional Atmospheric Modelling System and then entered in a weather generator to produce as many synthetic meteorological time series of 150 years each (Ps and Fs), to be used as inputs in agronomic and livestock models. Through these models, variables like crop and livestock input requirements and productive responses were predicted on annual base in both scenarios and then used to estimate the corresponding PDFs, whose shifts going from Ps to Fs allowed to quantify the impact of CCV on them.

This interdisciplinary approach was applied to a case study which is one of the regional pilots in the JPI FACCE MACSUR Knowledge hub1. It is located in an agricultural district characterized by a variety of farming systems covering a wide range of situations under both irrigated and rainfed Mediterranean conditions. Therefore, a variety of issues generated by the interaction of CC seasonal impacts on different cropping and livestock systems were deeply explored and analysed.

Our hypothesis is that the represented farming systems and the results obtained with the proposed approach can provide a relevant support for the development of effective and strategic adaptive responses in the transition to future climate far beyond the analysed local context, for the whole Mediterranean region. This also justifies the short-term time horizon chosen for the analysis, which addresses the CCV that can be immediately relevant for the development of strategic adaptation policies in the context of rural development.

2. MATERIALS AND METHODS

2.1. Study area and data sources

The study area is a 54,000 ha farming district located in the center-west of Sardinia (Italy). The agricultural system was reconstructed with reference to the situation of the year 2010, using the data of the Italian 6th General Agricultural Census, of the Farm Accountancy Data Network (FADN), and of a Water User Association (WUA), Consorzio di Bonifica e Irrigazione dell’Oristanese, that supplies irrigation water to part of the area. The productive conditions of crops and livestock in this area were derived from interviews to farmers, agronomists leaders of the Regional administration and of the local agricultural cooperatives. Labour, chemicals and water requirements were defined for the various stages of crop cycles, and expected yields were defined. Similarly, feed requirements of the various livestock categories were specified, with the actual food rations and the products obtained. The prices of the production factors were also collected.

The agricultural district under study can be divided in two sub-zones depending on the availability of irrigation water. In the irrigated sub-zone, the WUA supplies water from the Eleonora d’Arborea dam, which provides a reservoir of some 450 Mm^3, of which 120 Mm^3 are yearly made available to potentially irrigate 36,000 ha. The main irrigated cropping systems are based on cereals, particularly silage maize and rice, and other forage crops, mainly alfalfa and Italian ryegrass, but includes also horticultural crops such as artichokes, watermelon and tomatoes, citrus orchards, olives and vineyards. The most important dairy cattle

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[1] http://macsur.eu/index.php/regional-case-studies

breeding district in the island operates in the WUA sub-zone (Arborea district), with a well-organized cooperative system for production, processing and marketing of milk. The rain-fed sub-zone covers some 18,000 ha where occasionally a limited amount of water is available, withdrawn from wells in some farms. In this sub-zone 55% of the agricultural land is made of pastures, tares, woods or set-aside fields. The dairy sheep sector is largely present in this sub-zone and involves some 372,000 sheep and a number of small sheep milk processing plants.

Structural and economic features of the farms of this area were represented in the economic model by 13 farm typologies, identified on the basis of data from the FADN and the Agricultural Census.

2.2. The Discrete Stochastic Programming model

The DSP model has been used for analysing farmers' sequential decision making under uncertainty (McCarl and Spreen, 1997).

Cocks (1968) developed a multistage farming model in which labour requirements and gross margin are stochastic decision variables with discrete probability distributions. Rae (1971) further elaborated the capability of DSP in solving problems with sequential decisions under uncertainty. Adesina and Sanders (1991) and Shapiro et al. (1993) used this modelling technique to show that peasant farmers in Niger have the ability to adapt cropping and resource management strategies to the rainfall pattern. Lopez-Pereira et al. (1994) determined the income effects of soil conservation strategies and seed–fertilizer technologies in Honduras. More recently, Maatman et al. (2002) applied a sequential programming approach to describe farmers' decision making in Burkina Faso regarding grain consumption, sales, storage, and purchases throughout the growing and postharvest seasons.

Calatrava and Garrido (2005) used DSP to model farmer's behaviour and water markets exchanges equilibrium under uncertain water supply.

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.

Li et al (2015) used a hybrid methodology of interval parameter programming, conditional value-at-risk measure, and a general two-stage stochastic programming framework. The method extends the traditional two-stage stochastic programming by enabling uncertainties presented as probability density functions and discrete intervals to be effectively incorporated within the optimization framework. It could not only provide information on the benefits of the allocation plan to the decision makers but also measure the extreme expected loss on the second-stage penalty cost. The developed model was applied to a hypothetical case of water resources management.

Coulibaly et al (2015) develop a three-stage DSP model to consider the marketing decision of postponing selling after the recovery of cereal prices from the post-harvest collapse. This study takes into account dynamic price uncertainties as well as yield variability in analysing farmers' production, inventory and marketing decisions over time. Conditional strategies allow future decisions to be influenced by past decisions (Preckel, 2008). Moreover, randomness in the constraint parameters is also incorporated.

Applications of DSP have considered the effects of change in a single climatic component. Dono and Mazzapicchio (2010) and Connor et al., (2009) applied a two-stage model to evaluate the variation of two climatic components. Dono et al. (2013) consider three stages with uncertainty concerning the availability of water in dam and irrigation needs. Crean et al (2013) developed a DSP model of a representative wheat–sheep (mixed) farm in the Central West of NSW. More explicit recognition of climatic states and associated state-contingent responses, led to optimal farm plans that were more profitable on average and less prone to the effects of variations in climate than comparable farm plans based on the expected value framework.

In decision-making process, some variables are uncertain when farmers plan the annual activity, occurring in the subsequent months (stages), when they can take different values (states of nature) affecting the next steps and the productive results in different ways. So, when planning, farmers can only assign a probability to each state and define corrective actions to continue at best the production activity in the various cases. According to the DSP, farmers plan the activity based on the state with the highest expected income, calculated taking into account its optimal and suboptimal results. The optimal result is achieved if planning is based on a state of nature, and it really occurs; suboptimal results happen when other states occur. To plan considering the chance of suboptimal results leads to precautionary choices, resulting in an lower income than that would have occurred in a context of certainty, that considers only the optimal solution. This cost of uncertainty may increase if CCV modifies the probability or the representative values of the various states: so, its impact can be evaluated by comparing the results of the DSP model under Ps and Fs. A general representation of a DSP model under the agro-climatic uncertainty may be as follows:

$$\max_{x_{n_s}, cr_{n_s}, ca_{n_s}} z = \sum_s P_s * (GI_s * x_{n_s} - C_{cr} * cr_{n_s} - C_{ca} * ca_{n_s}) \qquad (1)$$

subject to

$$A_s * x_{n_s} \leq B_s + cr_{n_s} \qquad \forall s \qquad (2)$$

$$x_{n_s} = x_{n+1_s} \qquad \forall s \qquad (3)$$

$$N_s * Y_s * x_{n_s} + ca_{n_s} \geq R_s \qquad \forall s \qquad (4)$$

$$x_{n_s} \geq 0, cr_{n_s} \geq 0 \; and \; ca_{n_s} \geq 0 \qquad \forall s \qquad (5)$$

The decision-making is modelled in (n) stages, with (s) states of nature for uncertain variables. The variables relate to land allocation (x_{n_s}), and possible corrective actions (cr_{n_s}, ca_{n_s}). Equation (1) is the objective function, with expected gross income (z) that weights the values in the states of nature for their probabilities (Ps). Uncertainty involves gross margins (GI_s), allocation of land among crops (x_{n_s}), and corrective actions (cr_{n_s}, ca_{n_s}). Constraint (2) shows that uncertainty can affect A_s and B_s, ie matrix of technology and availability of resources, and that choices can involve land allocation, x_{n_s}, and corrective actions, cr_{n_s}, in stages (n) and states (s). Constraint (3) ensures that choices of previous stages affect subsequent. Constraint (4) affects animal feeding: N_s, Y_s e R_s are the unitary contributions of nutritional elements, crop yields, and nutritional needs of cattle categories. Corrective actions ca_{n_s} can be done at stage (n) for state (s). The number of stages, parameters and variables depends on the case study.

The present study considers uncertainty on the water needs of irrigated crops and on the yields of forage and grain crops cultivated in irrigated and rainfed zones. Therefore, the corrective actions modify the use of groundwater and the purchase of feeds and fodder. PDFs of the different crop variables (yields and water requirements) in both Ps and Fs were estimated through a maximum likelihood algorithm (software @Risk v. 5.7) and arbitrarily divided into three states, with 25% probability for low and high states, and 50% for intermediate. The arithmetic mean of the values assumed by each variable in the synthetic years lying within each state was used as its representative value. The PDFs discretized in such way were assumed to represent farmers' expectations on the state of the respective variable and the representativevalues and probabilityof the states derived from each PDF were entered in the model (Dono et al., *forthcoming*).

The DSP procedure was not used to model the effects of climate on livestock mortality, yields and quality of cow's milk, and yield of sale crops as rice. This because farmers have no chance to correct those effects once occurred, or is still difficult to assess results and costs of the mitigation actions. In such cases, the model considers only the average effect under present and future climate.

The DSP model was calibrated to base year 2010 with PMP approach of Röhm and Dabbert (2003): it better represents the choices among technically similar crops, with substitution elasticity higher that among different crops, and was useful to model the choice between cultivars of maize.

2.3. Uncertain agro-climate variables with DSP modeling of management

The DSP model reproduces the decision-making of farmers for the main agricultural and livestock activities burdened by climatic uncertainty. This uncertainty changes going from Ps to Fs and it is interesting to compare the results obtained under both of them to check if the farmers' possibilities to adapt decrease in this transition, generating income losses. Table 1 shows the main topics of management under agro-climatic uncertainty represented in this DSP model, the variables involved, the stage of the decision-making process to which they belong and the adjustment actions provided. Some topics are relevant in the hilly areas not provided by collective irrigation systems, i.e. the effects of climate uncertainty on fodder production for dairy sheep farms. Others refer to the relations between climate uncertainty and irrigation needs of intensive crops, which are basic for the intensive agricultural areas of the plains. Let's see them in detail.

Agro-climatic uncertainty affects ovine breeding of hilly areas by varying grazing yields in Fall and Spring, and grasslands yields for hay production: insufficient pastures to feed herds requires fodder purchasing, or using more stocks of hay. The stocks are restored with the Spring production of meadows, which is also uncertain. A three-stage DSP model represents the consequences of this on the choices of the ovine farms. The first stage concerns the allocation of land between cereal crops, forage and pasture at the end of Summer, given uncertain expectations on pastures (Autumn-Winter and Spring) and grasslands (hay), and known nutritional needs of the bred heads. The second stage is generated when farmers, known the yields of the Autumn-Winter pastures, may choose to compensate for shortages by drawing on the stock of hay or buying fodder. At this stage are still uncertain the Spring yields of pastures and of grasslands for replenishing stocks of hay. Furthermore, the use of hay in Winter influences the choices of Spring, when only the residues of the stocks will be available. The third stage is in Spring when is resolved uncertainty about the yields of pastures and hay from grasslands, and shortages can be compensated purchasing fodder.

In areas supplied of water by the *Eleonora d'Arborea* dam, two topics of management under climate uncertainty are regarded: irrigation needs of crops and yields of fodder to feed dairy cattle.

The first topic concerns allocation of water for the agriculture of the dam (a known volume) given the uncertainty about the irrigation requirements of crops, divided into fodder and crops sale. Management implications of this uncertainty are represented with a three stages DSP model. In the first stage in late Summer land is allocated among crops with uncertain expectations about irrigation requirements of crops in the following year. A first uncertainty is resolved in April-May when irrigation needs of ryegrass become known and can be satisfied with the stock water in the dam, or by drawing on to aquifers, and by bearing the related costs of lifting. This possibility determines the second stage of the decision-making process, where irrigation requirements of Summer crops are still uncertain and independent from the just occurred needs of ryegrass. Also, using water of dam will affect the chances of the next period, leaving it only a residue of the stock. Summer irrigation needs become known in June-August, and should weather conditions make them so high as to make insufficient the water dam, farmers can tap into aquifers, with the associated costs. This chance to offset an adverse agro-climatic condition determines the third stage of decision-making.

The second topic is specific to the dairy farms that must satisfy the feed requirements of dairy cattle (known) given the uncertainty about the yields of fodder grown on farms: soil has to be allocated with uncertain yields of ryegrass, corn silage and alfalfa that may require higher costs for purchases of fodder and feed. In this case, differently from the previous, it is not estimated a direct link between yield of fodder crops and climate conditions, and yields in the three states of water requirements (low, medium and high) are considered. In other words, farmer is supposed not to evaluate the direct link between yields and climate course, but to assesses the link between climate and water needs of fodder crops. In fact, irrigated fodder is produced with intensive intakes of water and chemical factors, and yields variability is not related to the course of temperatures and rainfall, unlike for rain-fed crops in the hills. Irrigation needs become the sorting variable, implying that crop yields may also be ordered in the opposite direction to it, i.e. with lower yields at higher water needs, and vice versa. In the first stage farmer allocates soil according to uncertain expectations on yields of ryegrass, corn and alfalfa, and knowing that fodder and feed can be bought to compensate possible shortages of farm production. Possibility of buying generates the second and third stages of the decision-making, respectively placed in Spring, when the yields of ryegrass become known, and at the end of Summer, at the occurrence of corn and alfalfa yields.

In Table 1 a schematization of these topics is provided, with reference to the activities performed in the whole area which were considered subjected to uncertainty.

Table 1. Main topics of management under agro-climatic uncertainty represented in this DSP model, variables involved, stage of the decision-making and adjustment actions provided

Management Issues	Uncertain *Discredited* Variable	DSP Stages	Corrective Actions
Meet nutritional needs of flocks, given uncertainties on yields of pastures in Fall and Spring, and on hay production.	Autumn grazing yields of pasture	I: land allocation, uncertainty on Autumn and Spring grazing yields, and Spring hay yields II: known Autumn grazing yield III: known Spring yield of grazing and hay	Use stocks of hay and buy feed in Autumn, at additional costs, when lowest yields of grazing prevent meeting nutritional needs of flocks.
	Autumn grazing yields of hay-crop		
	Spring grazing yields of pasture		Use residual stocks of hay and buy feed in Spring/Summer, at additional costs, when lowest yields of grazing prevent meeting nutritional needs of flocks
	Spring yields of hay-crop		
Allocate water of dam with uncertain irrigation needs of crops	Irrigation needs of ryegrass in April-May	I: land allocation, uncertainty on irrigation needs of ryegrass and Summer crops II: known irrigation need of ryegrass III: known irrigation need of Summer crops	Take groundwater, at additionalcosts, when higher irrigation requirements generate scarcity of water dam
	Irrigation needs of Summer crops in June-August		
Meet nutritional needs of dairy cattle with uncertain yields of farm's fodder	Yields of ryegrass, connected to its irrigation needs	I:land allocation, uncertainty on yields of ryegrass and summer fodder crops II: known yield of ryegrass III: known yield of summer fodder crops	Buy feed, atadditionalcosts, when lowest yields of farm's fodderprevent meeting nutritional needs of the livestock
	Yields of corn silage and alfalfa, connected to their irrigation needs		

2.4. Uncertain agro-climate variables without DSP modeling of their management.

The model does not represent the management of some variables with DSP, even if these appreciably change throughout the year, and in the transition from current to the future climate. This is the case of the cow milk production, its quality levels and price, cattle mortality in the Summer. This happens because, despite the link between changes in temperature and humidity, synthesized by the TH index, and the level of those variables, it was not possible to properly assess the costs of the corrective actions that breeders could undertake and, above all, their effects. So, stages and states of the DSP management were not modelled for those variables and only the economic effects were valued for the change in their average value in the transition from Ps to Fs. Also, the average value of cattle mortality is considered, under both the scenarios. However, these values are associated with different shares of comeback to keep constant milk production. This modifies nutritional needs of the herd, given the different needs of the demographic categories of cattle, resulting in a different allocation of land in dairy farms, which is generated according to the DSP criteria.

Finally, rice yields do not change appreciably in dependence on the various levels of irrigation requirements, therefore only the mean change is considered in the transition from Ps to Fs, with the economic impact on the activity.

3. RESULTS

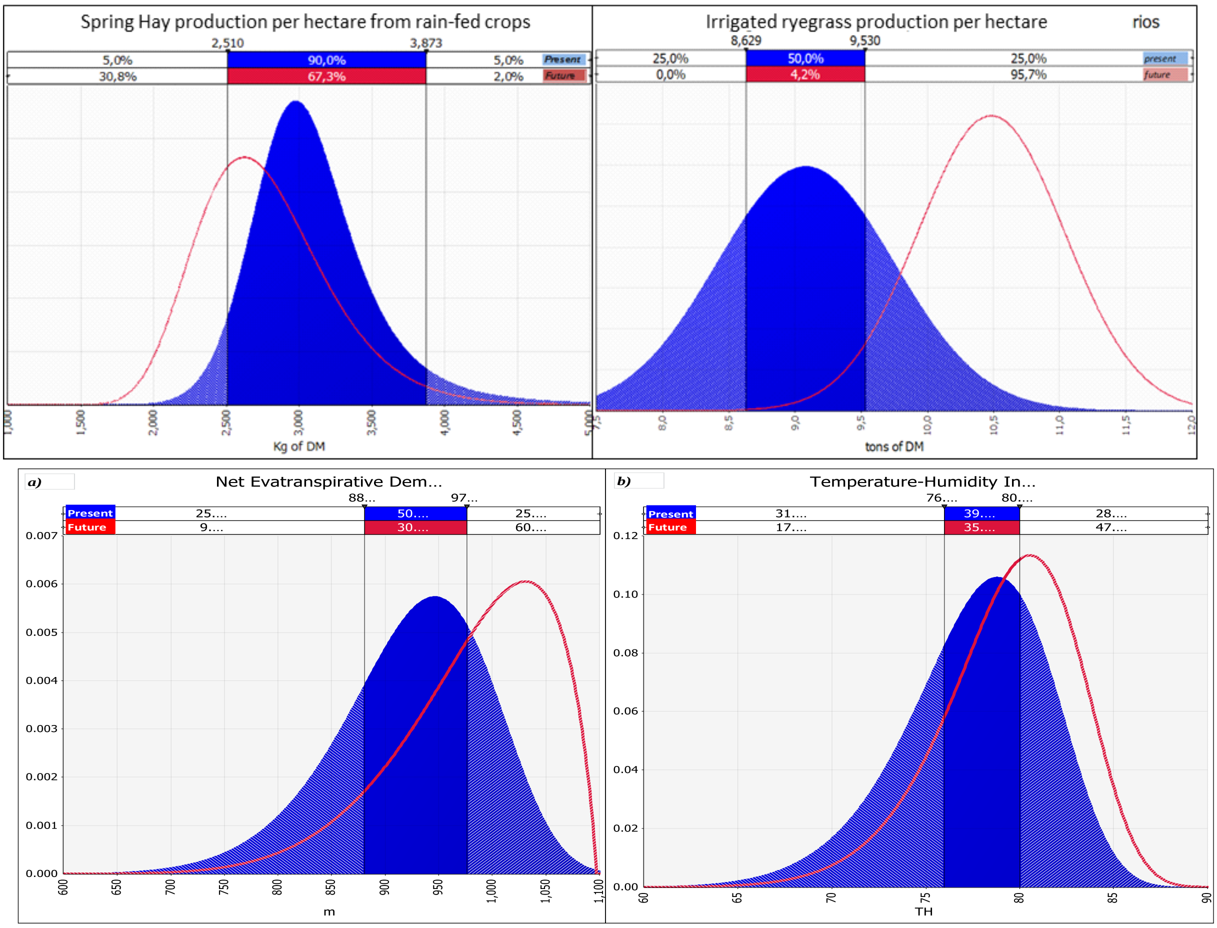
3.1. Impact of CCV on crop yields, irrigation needs and livestock performance

In fig. 1 are represented the PDFs of the agro-climatic variables modelled with the DSP approach in the present study. It can also be observed the shift of these PDFs from the present (solid blue) to the future climate (red line). The first two PDFs relate to the dry matter per hectare (DM/Ha) of grasslands hay. Under rainfed conditions, the probability of harvesting less than 2.5 t DM ha-1 rose from 5% under present climate to 30.8% under future climate. Conversely, the probability of intermediate yields dropped from 90% to 67.3%, and that of abundant yields dropped from 5% to 2%. This result was the consequence of the expected reduced rainfall and increased temperatures in spring, when the grass growth rate is at its maximum potential, but is constrained by the increased water stress under future climate and rainfed conditions . Note that these losses occurred despite the simulations of the future climate were run under higher atmospheric CO_2 concentration (408 ppm instead of 380 ppm). The second graph in Figure 1 shows that removing the water stress by imposing automatic irrigation, this impact of CCV was reversed and the probability of high DM yields for Italian ryegrass increased from 25% under present climate to 95.7% under the future climate (as an effect of the higher CO_2 concentration).

The third graph shows the impact of rising temperatures and reduced rainfall on Etn from the end of spring to early summer, which corresponds to the irrigation season. Note that the increased probability of high irrigation needs shifted from 25% to 60% when moving from Ps to Fs. The opposite happened for the states with lower irrigation needs. The shift of Etn is supposed to proportionally affect irrigation needs of fruit, vegetables and other sale crops. However, this trend was also found for ryegrass, silage maize and alfalfa, whose irrigation needs PDFs were directly estimated.

The PDFs of summer THI showed an increased probability of high states values under Fs respect to Ps. The probability of occurrence of THI values greater than 76, which corresponds to dramatic drops in the milk production per cow, increased from 68.6% under present climate to 82.4% under future climate. Similarly, the probability of occurrence of THI values greater than 80, which corresponds to higher livestock mortality, shifted from 28.8% to 47.1% under present and future climate respectively.

Figure 1. Current and Future PDFs for: Spring hay yield of rainfed crops, Irrigated ryegrass yield, Etn (April to August), THI (June-August).



3.2. Results of the DSP model: income of the area and of the farm types

With regard to the total area, under the Future scenario a limited reduction of net income, -2.6%, is expected (tab. 2). However, major differences arise between the impact of CCV in the irrigated area (WUA) and in the rainfed zone where the net income is expected to decrease by 5.4%.

Table 2. Economic results for the present climatic scenario, absolute values (000 €), and future climatic scenario, [percentage changes of future over current (%Δ)] for the total case study area, the irrigated sub-zone served by *WUA facilities* and the *rainfed* sub-zone.

	Current scenario (000 €)			Future scenario (%Δ)		
	Total	*WUA*	*Rainfed*	*Total*	*WUA*	*Rainfed*
Total revenues	204,730	179,050	25,680	-0.3	-0.4	0.8
Variable costs	130,010	114,024	15,986	1.1	0.5	5.5
Technical means	*67,796*	*61,798*	*5,998*	*1.5*	*0.8*	*8.1*
Feed	*23,067*	*19,008*	*4,059*	*0.7*	*-5.4*	*29.3*
Extra-farm labor	*7,738*	*5,707*	*2,031*	*-2.6*	*-0.6*	*-8.0*
Payments to the WUA	*2,144*	*2,107*	*37*	*1.2*	*1.2*	*0.0*
Water pumping from farm wells	*278*	*121*	*156*	*0.5*	*-0.2*	*1.0*
Gross margin	106,365	89,095	17,270	-1.9	-1.5	-3.8
Net income	78,078	65,945	12,134	-2.6	-2.1	-5.4

The decline of NI in the irrigated sub-zone was due to a small percentage reduction in total revenues and to an analogous percentage increase in variable costs. The decrease of revenues was mainly due to the reduction of cow's milk production that appreciably affected sales and profitability of the dairy cattle farms (Table 3). This is partially compensated by the significant decrease in the feed purchase due to the expected rise in farm fodder yields, which however is achieved by increasing the use of chemical inputs and by expanding the irrigated area with water from the WUA, as evidenced by the increases the respective cost components. The negative effects of all these changes affected almost exclusively the two types of dairy cow farms, which suffered a -5 to -6% reduction of net income (Table 3). Other farm types in the WUA sub-zone benefited by increases of NI especially due to the increased cereal yields, generated by the CO_2 fertilization effect. In the case of rice-growing farms, the effect on the rice crop yield is really significant and the same is true for the net income of these farms (Table 3).

The NI decline in the rainfed zone was caused by an increase of variable costs greater than the expected increase in revenues. This latter is generated by the increase in the cereal yields that in turn increased net sales of the arable crops types. In this area there are, however, the harsh consequences of the reduction in the fodder production from grasslands and hay-crops for sheep, which notably increased the purchases of feed and hay, greatly compressing the income of the ovine typologies, and hence of the entire zone. The only sheep farm types that suffered a less dramatic reduction of NI was that served by the WUA, as irrigation allowed to fully exploit the higher winter temperature and CO_2 fertilization effects. All these impacts led to a further widening of the gap between the profitability of the rainfed vs irrigated sub-zones. Under future climate scenarios, the net income per unit of family labour in the rainfed zone is expected to be less than half of that obtainable in the WUA zone (€ 13.260 against € 27.241, not reported in the table).

Table 3 . Net Income per typology and farm: *present climate scenario* [absolute values (000 €)] and *future* climate scenario [percentage changes of future over current (%Δ)]

	Current scenario (000 €)		Future scenario (%Δ)
	Typology	Representative farm	
Rice	4,097	170.7	9.9
Citrus	2,670	39.3	-0.01
Cattle A	26,355	202.7	-5.1
Cattle B	6,825	170.6	-5.9
Greenhouse	1,231	26.8	0.4
Vegetables - Cereals	18,656	33.2	-0.8
Cereals – Forages	4,902	89.1	2.2
Tree and arable crops	1,209	12.1	0.04
Vegetables – Fruit	1,014	10.1	-0.04
Cereals - Forages	2,691	28.6	0.01
Sheep A	2,461	54.7	-5.3
Sheep B	1,984	10.5	-11.8
Sheep C	3,984	30.9	-7.4

4. CONCLUSIONS

The interdisciplinary modelling approach adopted for this study allowed the integrated assessment of the expected impacts of CCV over a wide range of farming systems under Mediterranean conditions. The chosen approach was not a cascade, i.e. by identifying first the climate alterations, and proceeding along the agricultural-livestock-economic chain. Instead, the crucial phases of the cropping systems were identified, and farm management understood from the farmers' perspective, to test their sensitivity to change. Under Mediterranean rainfed conditions, the expected increase in summer temperatures is unimportant to those production systems that had been designed according to the certainty that in this period crop growth is near to zero due to the characteristic summer drought. This is the case of the rainfed dairy sheep farming system, that is managed to minimize the flock feed requirements in summer. Instead, other changes, perhaps less considered, can be particularly relevant, namely the increased temperatures and reduced rainfall in the spring, which result into lower hay-crop yields and hence higher vulnerability of rainfed livestock farming systems. The need to focus on specific aspects of CCV that are most worth to be considered as they may be reveal gaps in the adaptive capacity of the different farming systems, is an important conclusion of this study. In contrast, a limitation of this study is that it was not focused on the role of extreme weather events, disasters, which impede or destroy the production cycles, rather than altering them.

Also, this agricultural perspective focused the study on the influence of CV on the production performance of crops and livestock, which are relevant for farm management. Thus, the impacts of CCV on the production and on the agricultural economy were assessed by simulating the actual possibilities of adaptation of farmers to a new climatic scenario.

The main results showed different impacts on irrigated and rainfed sub-zones. Livestock systems relying on rainfed sub-zones proved to be most vulnerable to a reduction of the net farm income that could hamper their ability to continue their business: family farm income per unit of labour was reduced to less than half of that achieved in the irrigated sub-zone. The main weakness of those activities, especially the forage production in the sheep farms, is in the lack of flexibility in the access to water in the rainfed sub-zone, mainly because of the lack of irrigation infrastructures, given the abundant reservoir water availability managed by the WUA. Therefore, it may be vital either extend to those zones the irrigation infrastructure, or to facilitate the vertical integration of rainfed and irrigated districts to supply forage production at sustainable price in dry years.

The results of the analysis also indicate that the impact in the more intensively irrigated area is concentrated on dairy cattle farms and is mainly generated by the reduction of quantity and quality of milk production. This suggest to better explore and model the effects of increased temperature on milk production, including the adaptation options related to management aspects.

A final evidence regards some environmental impacts of the simulated changes. First, it should not be overlooked that more intensive use of chemical inputs can increase the environmental pressure in areas already intensively exploited. Furthermore, the increase in the groundwater use for irrigation may led to further environmental concerns in the rainfed zone. This kind of issues must be considered particularly worrying in Mediterranean region where the salinization of groundwater tables is increasingly determined by overexploitation and threatened by sea level rise generated by global warming. This calls for interventions and further research efforts towards the increase the efficiency of the WUA in providing their services and possibly extending to the currently non-served areas the supply of water from collective networks tapping on surface resources.

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