Winners and losers from climate change in agriculture: food security issues in the Mediterranean basin

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ABSTRACT

The Mediterranean region has always shown a marked inter-annual variability in seasonal weather, creating uncertainty in decisional processes of cultivation and livestock breeding. This should not be neglected when assessing the impact of climate change (CC), which modifies the atmospheric variability and generates new uncertainty conditions, and is particularly relevant when modelling the adaptive responses of farmers to the CC itself. Our analysis examines precisely this aspect by reconstructing the effects of inter-annual climate variability in a diversified agricultural district that represents a wide range of rain and irrigated agricultural systems in the Mediterranean. We generated the atmospheric variability conditions of ten years representative of present climate (2000-2010) and as many of near future (2020-2030) by processing the results of a Regional Atmospheric Modelling System. Then, we implemented calibrated crop and livestock models to estimate the corresponding productive responses in the form of probability distribution functions (PDFs) under the two climatic conditions. We assumed these PDFs able to represent the expectations of farmers in a discrete stochastic programming model that reproduced the economic behaviour of the main farm types operating in the study area under uncertainty conditions. The comparison of the results in the two scenarios provided an assessment of the impact of CC, also taking into account the possibility of adjustment allowed by present technologies and price regimes. Major differences in the economic response emerged among farm typologies and sub-zones of the study area. As discussed in a previous paper, a crucial element of differentiation is water availability, since only irrigated C3 crops can take advantage from the fertilization effect of increasing future atmospheric CO_2 concentration. Instead, the reduction of spring rainfall associated to the higher temperatures depresses the rainfed crop production. A dualism emerges between the smaller impact on crop production in the irrigated plain sub-zone, equipped with collective water networks and abundant irrigation resources, and the major negative impact in the hilly area, where these facilities and resources are absent. Yet, increasing summer temperatures also negatively affected milk production and quality, and cattle mortality of intensive dairy farming. In this latter paper, after summarizing those impacts, we focus on some repercussions of the CC on the supply of agricultural products. Interesting aspects emerge about the link between CC and food security in the context of an advanced agriculture in the Mediterranean.

Keywords: CC adaptation, Mediterranean-farming systems, integrated assessment, modelling approaches

1. Introduction

The meteorological conditions of a climatic zone often presents a significant inter-annual variability: this is true even in periods in which people perceive the climate as in a stable condition. Many studies mention and explain the determinants and expressions of climate variability in the various sections of the Mediterranean area (Navarra and Tubiana, 2013). The atmospheric circulation in the Atlantic Ocean determines the variability of rainfall in the autumn period (Altava-Ortiz et al., 2011). Heat waves are a frequent feature of the Mediterranean summer (Gaetani et al., 2012). In addition, several anomalous warm summers have occurred in the Mediterranean and in southern Europe over the last 60 years, with hot events of different intensities and lengths (Segnalini et al., 2011).

Climate variability influences crop production and livestock as extensively treated in the scientific literature. The relationships between variability in the climatic conditions and livestock production have been investigated with specific mathematical and statistical models (Vitali et al., 2009; Bernabucci et al., 2014). Agronomical models have provided a rich characterization of optimal growth to represent the response of crops production under different climatic conditions (Liu and Tao, 2013; Dono et al., 2013a, 2013b, 2014). Various studies have used these models 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; Olesen et al., 2011; Palosuo et al., 2011; Reidsma et al., 2010; Iglesias et al., 2009). In addition, there is a growing recognition that the aggregate results can hide large amounts of variability, and is important to evaluate the effects of Climate Change (CC), and the possible adaptation strategies, to the level of farming systems, or agricultural households (Claessens et al., 2012). In this regard, it is important to considering that farmers base their annual planning on expectations about crop and livestock production that depend on inherent variability of climate and will prove correct, or less, only several months later. Therefore, when assessing the impact of CC on agriculture, and possible adaptation strategies, it must be considered how they can alter their production choices also responding to the changes in the climate variability.

A recent paper presented the main characteristics and results of an integrated study on the effects of climate variability on crop and livestock production, and farm management of a diversified Mediterranean agricultural district (Dono et al., 2016). The analysis assessed the productive and economic impact of CC at farm typology level, including the effect of changing the variability of atmospheric conditions. The study area is located in the Oristano province in the central-west Sardinia (Italy), and it is one of the Regional Pilot case studies conducted under the research activity of the FACCE MACSUR Knowledge hub[1]. This agricultural district extends for 54,000 hectares (Ha) and presents a variety of farming systems covering a wide range of conditions under both irrigated and rainfed Mediterranean conditions. Therefore, many issues generated by the interaction of CC seasonal impacts on different cropping and livestock systems were deeply explored and analysed. Data from the sixth Census of Agriculture, 2010, and records from the FADN and the local Water Users Association (WUA) show that irrigation is practiced on 36,000 Ha of that territory. The main crops of this sub-area are wheat, corn and forage, and cow's milk is the key product. In addition, vegetables are common, as also rice, citrus, olive trees and vineyards. Additional 18,000 Ha are instead rain-fed and used for pasture and rye grass, for sheep milk production, woods and set-aside. This latter sub-zone uses farm wells to irrigate very limited areas.

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

The problems due to the change of agro-climatic conditions in this area were analysed by integrating climatological, agronomic and livestock models, whose outputs, once treated with statistical methods, were included in an economic model that simulates the farm choices under present and then future climate context. Our hypothesis is that the represented farming systems were also relevant to many other areas of the Mediterranean, and the results obtained can provide a relevant support for the development of contextualized effective and strategic adaptive responses far beyond the analysed local context, in the transition to future climate. This also justifies the short-term time horizon chosen for the analysis, which addresses the changes in climate variability that can be immediately relevant for the development of strategic adaptation policies in the context of rural development.

Dono et al. (2016) provides a detailed description of the analysis; following a summary of its main steps and the description of some further results that we report in this paper, and regard the biomass production of the main agricultural activities. This aspect seems relevant in the context of food security given the changes in crop yields and in milk production generated by the CC.

2. Materials and method

A Regional Atmospheric Modelling System (RAMS) nested into an atmosphere-ocean model based on ECHAM 5.4, generated the current and future climate scenarios of the Oristano area (Scoccimarro et al., 2011). We defined these scenarios with reference to a decade, and not compared to one year, just to induce the model RAMS to consider the variability inherent in the climate, and generate a wide spectrum of conditions that may arise. Therefore, the greenhouse gas scenario A1B of 2000–2010 denotes the current climate; the scenario A1B of 2020–2030 denotes the future climate. A post-processing procedure based on observed data and reconstructed sea surface temperature reduced the errors due to poor geo-morphological description (mountains, land cover) from numerical models. The outcomes of RAMS for the current and future climates were furtherly processed with the weather generator WXGEN to obtaining data for 150 stochastic years under each of the two scenarios. These data defined the entire range of inter-annual climate variability in that territory under the two climates. Comparing the two scenarios emerges that the footprint of CC is the increase of the summer daily temperature, maximum, but mostly minimum. Temperature increases slightly during the spring, and markedly in fall–winter. Rain variability increases, coupled to a reduced annual average.

The EPIC (Environmental Policy Integrated Climate) model was used to estimate the impact of temperature, rainfall and atmospheric CO_2 in the two scenarios on yields of irrigated (silage maize, ryegrass, alfalfa) and rain-fed (grasslands, hay crop) crops (Balkovic et al., 2013). The model calibration utilized crop, soil and climate data from field experiments, and interviews to farmers. The impacts of the two climates on cattle breeding were evaluated using equations derived from the literature on the relationship between the index of temperature and humidity (THI), mortality (Vitali et al., 2009), milk yields and its somatic cell content (Bertocchi et al., 2014). These relationships were estimated with linear regression analyses in two phases in Italian areas where the Holstein Friesian is bred similarly to the study area.

Those results were processed with maximum likelihood methods to estimate the probability distribution functions (PDF) of the yields, current and future, of pastures and grasslands in the rainfed zone, and of irrigation needs, and relative yields, of maize, ryegrass and alfalfa in the irrigated zone. The irrigation needs of the other crops were estimated based on their present values and the percentage change in *net evapotranspiration* of the future climate with respect to the present. The range of each PDF was divided into 3 *states*, with 25% probability for low and high states, and 50% for intermediate, which constitute the vector of probability (P) of each uncertain variable. The representative value of the variables in the three *states* is the average of their values in the synthetic years falling in each *state*.

Those values were used to represent farmers' expectations on the course of weather in the incoming season in a model of discrete stochastic programming (DSP) that simulates their annual planning under uncertainty on atmospheric conditions (Hardaker et al., 2004). According to this modelling scheme, farmers plan their choices considering the probabilities of the various *states of nature* that may arise in the course of the season, and the possibility to correct the decisions taken if unexpected *states* should occur. Applying corrective actions minimizes the impact of those conditions, even if at a cost (the cost of uncertainty) that causes sub-optimal results. DSP has been used to represent the economic impact of many agricultural uncertainties: availability of irrigation water (Calatrava and Garrido, 2005), productive results of technologies (Coulibaly et al., 2011), on weather risks (Mosnier et al., 2009), change in climate variability (Dono and Mazzapicchio, 2010).

Our DSP model represents the territorial agricultural supply based on 13 farm types (Dono et al., 2016). The climatically driven variability accounted for in this study relates to summer water needs of crops, spring yields of pasture and hay from grasslands, autumnal yields of pastures and of grazed grasslands. The corrective actions regard the pumping of irrigation water from wells in case of higher temperatures and water requirements of the crops, and the buying of feed in case of lower yields of fodder. The mathematical representation of the model is compactly defined as follows:

$$\max_{X_1, XR_{n_s}} z = GI\, X_1 - \sum_{n=2}^{N} \sum_{s=1}^{S} P_s\, Cr\, XR_{n_s} + Pm\, Qm \qquad (1)$$

subject to:

$$A\, X_1 \leq B \qquad (2)$$

$$A_s\, X_1 \leq B + \sum_{n=2}^{N} XR_{n_s} \qquad \forall s \qquad (3)$$

$$N\, Y_s\, X_1 + \sum_{n=2}^{N} XR_{n_s} \geq R \qquad \forall s \qquad (4)$$

$$X_1 \geq 0 \text{ and } XR_{n_s} \geq 0 \qquad \forall s \qquad (5)$$

n is the number of stages of the decision making and s are the *states of nature* that uncertain variables can assume; X_1 is land, whose allocation occurs in the first stage; XR_{n_s} are corrective actions performed in the subsequent states (n= 2,..,N) on the actual occurrence of one of the *states*. These actions modify the available additional resources, at a cost (Cr). Equation (1) is the objective function (z) that sums different components: gross margins (GI) of the activities chosen in the first stage (X_1); costs (Cr) of the corrective actions XR_{n_s}. In this last case, the values of the uncertain activities in the *states of nature* are weighted with their probabilities (P_s), and summed over the N stages. Finally, the objective function sums the revenues of milk, based on the price (Pm) and the total quantity (Qm) obtained under present climate and future[2]. Constraints (2) refer to land and

[2] The model sections dedicated to the allocation of land do not account for the effects of climate on the revenues of cow milk, which are considered in the objective function, as for crops to sale (rice, wheat and barley). The effects of climate

labour resources: A is the matrix of technical constraints and B is the quantity of available resources. Constraints (3) refer to the water resource and show that uncertainty affects A_s, i.e. watering needs of irrigated crops, and that choices involve corrective actions, XR_{n_s}, in stages (n) for each states (s). Constraints (4) refer to animal feeding: N are the unitary contributions of nutritional elements, R are the nutritional needs of livestock categories. The uncertainty affects Y_s, i.e. yields of forage crops, and that choices involve corrective actions, XR_{n_s}, in stages (n) for each states (s).

We calibrated the model to the reference year 2010 with the PMP approach of Rohm and Dabbert (2003) that models the choice between technically similar crops, whose mutual substitution elasticity is greater than that relating to other crops[3]. The calibration involved land allocation among crops decided in the first stage.

3. Results of the DSP model

The values of the three *states of nature*, and the respective probabilities were included in the DSP model that generated the productive and economic results under the two scenarios. Table 1 reports the results on the *biomass production* of the main crops in the present scenario, and their percentage changes in the future for the total study area and its two subzones. The table also shows the impact on cow milk production.

Table 1: biomass production under present and future climatic scenarios [percentage changes of future over current (%Δ)]: total area, zone irrigated by the *WUA* and *rainfed* zone.

	Present climate (Mg)			Future climate (%Δ)		
	Total	*WUA*	*Rainfed*	*Total*	*WUA*	*Rainfed*
Grain cereals	57,544	49,695	7,849	18.0	8.1	80.6
Durum wheat	*23,580*	*18,604*	*4,976*	*2.3*	*2.5*	*1.6*
Rice	*24,894*	*24,894*	*0*	*7.2*	*7.2*	-
Barley	*6,192*	*4,200*	*1,992*	*-5.5*	*-5.5*	*-5.4*
Maize	*1,000*	*860*	*140*	*110.9*	*129.9*	*-6.0*
Forage crops	644,648	490,209	154,439	-2.2	0.1	-9.6
Grasslands	*149,653*	*17,876*	*131,777*	*-7.2*	*-7.2*	*-7.2*
Hay crops	*36,067*	*16,005*	*20,062*	*-18.3*	*-8.2*	*-26.3*
Silage maize	*384,916*	*384,916*	*0*	*0.7*	*0.7*	-
Italian ryegrass	*31,655*	*31,434*	*221*	*34.6*	*34.0*	*127.1*
Alfalfa	*32,207*	*29,828*	*2,379*	*-31.0*	*-32.6*	*-10.0*
Triticale	*10,150*	*10,150*	*0*	*-3.2*	*-3.2*	-
Field horticultural crops	234,189	227,021	7,168	-0.2	-0.2	-0.1
Processing tomato	*154,800*	*152,160*	*2,640*	*-0.3*	*-0.3*	*-0.2*
Melon and watermelon	*57,029*	*53,847*	*3,183*	*-0.3*	*-0.3*	*0.0*
Potato	*5,158*	*5,088*	*70*	*3.6*	*3.7*	*-0.8*
Carrot	*5,119*	*5,119*	*0*	*6.3*	*6.3*	-
Early potato	*2,166*	*1,748*	*418*	*-8.2*	*-10.2*	*0.0*
Greenhouse crops	7,008	6,175	833	-1.6	-1.9	0.0
Tree crops	19,985	16,644	3,341	0.0	0.0	0.0
Cow milk	173,619	173,619	0.0	-1.2	-1.2	-
summer period	*25,271*	*25,271*		*-8.4*	*-8.4*	

Source: our elaborations and analyses on (Dono et al., 2016)

on costs of milk production are considered in sections on production and the purchase of fodder, for which, inter alia, are also provided corrective actions in case of adverse conditions. Similar corrective actions concern the sheep sector. In this case, however, the summer production of milk is irrelevant; therefore, the model neglects climate impacts.

[3] For more details, see Cortignani and Dono (2015).

Cereal production grows significantly across the study area; the largest increases are in rice and corn production that, due to irrigation, may benefit from the fertilization effect of the increase in atmospheric CO_2 concentration. Instead, the production of fodder reduces, with sharp falls mainly in the non-irrigated sub-area, where the decrease of the spring rains causes a drop in the yields of hay crops. On the contrary, water availability allows an appreciable increase of the productivity of the Italian ryegrass in the irrigated sub-area, thereby increasing the production of that crop in the beef and dairy farms, and in the sheep farms that manage some farmland in that sub-region. Also, the production of corn silage increases, due to the notable expansion of the late hybrid at shorter circle, which compensates the considerable drop of the variety that is currently widely cultivated. Minor changes affect vegetable crops: the appreciable contraction of early potatoes also depends on the choices of the dairy farms to expanding the acreage of the irrigated late hybrid of silage maize and of Italian ryegrass. The last lines of the table show the reduction in bovine milk: this is only due to the decrease in the unitary production, given that the simulation keeps fixed the number of bred cows. A relatively small reduction of the annual production emerges; the drop is instead quite impressive in the summer months.

These production variations contribute to generating the changes in net income (NI) in the two sub-areas that the table 2 identifies for various groups of farm types and their aggregates. Data show that the negative impacts in the irrigated sub-zone affect almost exclusively the dairy cattle farms that suffer a -5.3% average drop of NI. The decrease of revenues is mainly due to the reduction of cow’s milk production; however, this is partly offset by the decrease in the purchase of livestock feed due to the expected increase in farm fodder yields. Other types in this sub-zone benefited by increases of NI, due to the increased cereal yields from the CO_2 fertilization effect. In the rice-growing farms, the effect on the rice crop yield is notable, and the same applies to their NI.

Table 2: net income (NI) per group of representative farms in the present and future climate (000 €); percentage changes of future NI over present (% Δ NI)

	Present NI	Future NI	% Δ NI
Rice	4,317	4,718	9.3
Trees and arable crops	3,874	3,874	0.0
Dairy farms	33,180	31,433	-5.3
Mixed crops	23,500	23,459	-0.2
Irrigated zone	66,102	64,721	-2.1
Greenhouses	1,231	1,236	0.4
Mixed crops	3,733	3,730	-0.1
Sheep	7,903	7,230	-8.5
Rain-fed zone	11,636	10,961	-5.8
Total area	77,738	75,681	-2.6

Source: our elaborations and analyses on (Dono et al., 2016)

A larger reduction occurs for the NI of the rainfed area, due to an increase in variable costs that is more than proportional to the increase in revenues caused by higher grain yields and sales of arable crops. In particular, there are significant consequences of the reduction in the fodder production from grasslands and hay-crops: sheep farms had to notably increase purchases of feed and hay, which greatly compressed NI of these types and of the entire zone.

4. Discussion

The results showed that in the next 2020-30 decade the CC can generate different types of alterations of atmospheric conditions that are all relevant for the annual planning of agricultural activities under Mediterranean conditions. Those changes can be beneficial to some farm activities but unfavourable for others, thus leading to winners and losers under the same area and climatic pressures. Even within the same farm type, CC can generate impacts of different sign and intensity among different agricultural activities. For example, the decrease of spring hay yields offsets the increase in yield of grass meadows and pastures of sheep farms. Similarly, the decrease in milk production due to heat stress elides the potentially positive effects on income generated by the increase in irrigated fodder yields of dairy farms. However, magnitude and sign of the productive and economic impacts depend on the resource endowment of farms in the specific context, and the way access to them is regulated. For example, in rainfed areas the increased probability of high temperatures and low rainfall in the spring, has a negative impact on the fodder production and, therefore, increases the costs for purchasing fodder. On the contrary, the current, non-limiting availability of water resources in the WUA sub-zone, allows irrigated farms to escape the negative effects of spring drought on fodder production, and to take full advantage of the potential yield increase of C3 crop species due to the expected increased concentration of atmospheric CO_2. This results into higher yields, consistently with the results of other studies in Europe (Schönhart et al., 2014), and lower cost for fodder supply. This advantage at least partially compensates for other negative economic impacts of CC in dairy farms, due to the reduction of production and quality of milk in the summer months and increased mortality of livestock. This confirms the close relationship between the capability of adaptation to CC and farms' resource endowment, as evidenced by Antle et al. (2004) for northern USA farming systems. Similarly, Reidsma et al. (2010) conclude that the heterogeneity of the income impacts of the CC on EU agriculture, at both regional and farm levels, and the adaptation capacity largely depends on the characteristics of the farms (size, intensity and kind of land use) in the same region. We found this evidence particularly true for the Mediterranean context.

Our results show that in some cases available technologies provide considerable opportunities for adaptation, as already found in other studies (Shrestha et al, 2013). For example, the availability of a wide range of silage maize hybrids with different degree of earliness can contribute to mitigate the impact of higher temperatures prolonging the duration of the crop production cycle, and thus maintaining substantially unchanged the current crop yield level. The criteria used to manage the resources influence this flexibility. The peculiar water payment system "hectare-culture" (i.e. the cost of water depends on the type of crop and not the actual use water) implies that only the variation in the irrigated area, and not also in the amount of water used, affects the cost of using the resource (and the payments to WUA) (Dono and Giraldo, 2012).

On some important aspects these results only give helpful hints, but no clear indications. In fact, the structure of the model we used, which is a local agricultural supply model, does not allow defining the productive implications due to CC on market prices, along the food chain, as well as the relationships with buyers of agricultural products and suppliers of agricultural raw materials. For instance, the 8.4% reduction in the production of milk in the summer months may generate problems in the cheese-making, which also suffers because of a reduction in the quality of milk[4]. This is important for the study area because the summer sales of fresh dairy products are financially very relevant to the cooperative cheesemaking company that uses the totality of the milk produced in the area, and is the leading producer of these foods in Sardinia. The problem will have wider repercussions if the decline in milk summer production will be generalized to the north of the Mediterranean area: this might affect the summer production of many cheeses with protected

[4] Another impact of the CC reported in Dono et al. (2016)

designation of origin in those territories. Conversely, a generalized increase in the supply of cereals from other, more important, areas of production may reduce market prices, reducing the positive effects indicated by our model for the farms involved in those productions. Similarly, the reduction in the production of some fodder and the increase of their demand may increase prices, as well as the demand for land rented for their production, with further negative effects on the budget of livestock farms.

5. Conclusions

The interdisciplinary modelling approach adopted for this study allowed an integrated assessment of the expected impacts of CC over a wide range of farming systems under Mediterranean conditions. This approach assessed the sensitivity to CC by identifying the crucial phases of the cropping systems, and by framing the agricultural management issues from the farmers' perspective. Under rainfed conditions, the expected increase in summer temperatures might only slightly affect farming systems that are already designed considering a summer drought condition. This is the case of the sheep farming in rainfed conditions, which is often already managed for minimizing the requirements of feed of the flocks in the summer. Instead, other changes, sometimes neglected, might be particularly relevant. This is the case of the increased temperatures and reduced rainfall in spring, which reduce the hay-crop yields, hence increasing the vulnerability of rainfed livestock farming systems.

The need to focus on specific aspects of CC that are most worth to consider as they may 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 the absence of connection with the CC effects on market balance, and on the productive relationships between agriculture and other segments of the supply chain of agricultural production. The local supply model used for this analysis assumes, in fact, that the prices of inputs and outputs remain unchanged, and this hypothesis can be restrictive if we assume that the model can represent the CC agricultural effects in a wider area. Of course, for some industries, even a large area such as the Mediterranean has little influence on the market balances; for others, changes in local agricultural productivity and supply may however influence prices. At this time within the MACSUR project, we are just trying to consider the set of these market effects, integrating the results of local models like this with the results of the CAPRI model (www.capri-model.org), which can simulate the change of market balances and the more general climate impacts.

Overall, however, the outcomes of this study suggest that the challenges posed by CC in the near future require more than just a more efficient management of resources at local scales. Effective adaptation pathways may emerge from a strategic long-term contextualized visionary perspective of the future of agriculture, emerging from the integration of scientific and lay knowledge (Nguyen et al, 2014). This is particularly important in the vulnerable areas of the world such as the Mediterranean basin.

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