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Perceptions of Present and Future Climate Change Impacts on Water Availability for Agricultural Systems in the Western Mediterranean Region

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Abstract: Many Mediterranean countries have experienced water shortages during the last 20 years and future climate change projections foresee further pressure on water resources. This will have significant implications for irrigation water management in agricultural systems in the future. Through qualitative and quantitative empirical research methods carried out on a case study on four Mediterranean farming systems located in Oristano, Italy, we sought to understand the relationship between farmers' perceptions of climate change (i.e., increased temperature and decreased precipitation) and of present and future water availability for agriculture as forecasted by climatic and crop models. We also explored asymmetries between farmers' perceptions and present and future climate change and water scenarios as well as factors influencing perceptions. Our hypotheses were that farmers' perceptions are the main drivers of actual water management practices and that sustainable practices can emerge from learning spaces designed from the understanding of the gaps between perceptions and scientific evidences. Results showed that most farmers perceived that climate change is occurring or will occur in their area. They also perceived that there has been an increased temperature trend, but also increased precipitation. Therefore, they are convinced that they have and will have enough irrigation water for agriculture in the near future, while climate change projections foresee an increasing pressure on water resources in the Mediterranean region. Such results suggest the need for (i) irrigation management policies that take into account farmers' perceptions in order to promote virtuous behaviors and improve irrigation water use efficiency; (ii) new, well-designed learning spaces to improve the understanding on climate change expectations in the near future in order to support effective adaptive responses at the farm and catchment scales.

Keywords: climate scenarios; crop irrigation water requirement; impact scenarios; farmers' knowledge; farmers' beliefs

1. Introduction

Future climate change projections foresee increasing pressure on water resources in the Mediterranean region. Many Mediterranean countries have experienced water shortages during the last 20 years [1]. The regional climate has evolved during the last decades. Since the late 1970s, the mean annual temperature has increased by 0.1 °C per decade and precipitation decreased by 25 mm per decade [2]. Since the 1960s, the whole Mediterranean basin has experienced warmer conditions [3,4] and decreasing precipitation [2,5,6]. According to the IPCC 2007 [7], temperature is expected to rise by 2–3 °C and annual precipitation to decrease on average by 30% by the year 2050. The combination of increasing temperature and decreasing precipitation could cause more intense and more frequent drought periods as well as induce a net decrease in freshwater availability [1].

In Mediterranean areas, agriculture is the largest consumer of fresh water and in some cases is threatening the availability of water resources for other uses [8]. The potential impacts of climate change are becoming more and more noticeable and costly and have strong implications for changes in water management policies, agricultural practices, and water use. Research on adaptation of agricultural systems to climate change has mainly focused on weather patterns and extreme events [9] as well as the importance of projected climate change scenarios [10], future impacts of climate change and response strategies [11,12], and policy and institutional frameworks to improve adaptations [13,14]. Moreover, an increasing number of studies in the last decade has emphasized the key features of adaptation in agriculture including how farmers perceive, experience, and believe in climate change and adaptation (e.g., [15–18]). An effective response to climate change requires an understanding of the perceptions of individuals [15,19] and the successful up-scaling of local adaptation into the international policy arena [20]. Failure to consider farmers' perceptions and key drivers of climate impact beliefs as well as adaptation attitudes would lead to failure in the development of effective and sustainable adaptive strategies.

In this research, we studied farmers' perception of climate change and their concerns about water availability in the Oristano province, Sardinia, Italy. We sought to understand the relationship between farmers' perceptions of climate change (i.e., increased temperature and decreased precipitation), its impacts, and their experience and beliefs on present and future water availability for agriculture. We also explored the asymmetries between farmers' perceptions and beliefs and present and future climate change and water scenarios, as well as the factors influencing farmers' beliefs and concerns about future water availability. Our research aimed to suggest that farmers' perceptions can influence water management practices and that sustainable practices can emerge from learning spaces designed from the understanding of the gaps between perceptions and scientific evidences. The ultimate goal is to inform policymakers and stakeholders about the implications of farmers' perceptions of climate change and water resources that would support future developments of irrigation management policies including synergies and trade-offs, taking into account farmers' water-efficient management practices.

2. Conceptual Background

Research on understanding local perceptions of climate variability and its impacts is important for supporting the development of climate change adaptation policy at the local scale [21]. Agricultural livelihoods are dependent on the weather, therefore farmers pay attention to the variability of local weather and climate, and indeed they tend to notice changes. The changes in weather and climate that farmers perceive have the most direct effect on their production activities [22,23]. Research around the world reported and confirmed the assumption of how people use personal experience to detect their local climate changes, especially in agricultural production (e.g., [15,24–26]). Perception is meant here as "the detection of information" ([27] p. 224). Farmers create their personal views of reality through receiving direct information from personal sensory impressions of the environment around them and interpreting it according to factors such as their own interest, the local sociopolitical background, knowledge, and experiences [15]. They use this reality to shape their understanding of the environment and translate it into behavioral responses. However, farmers of the same community may identify different changes depending on their production activity and perceived changes may not always reflect reality and may be misinterpreted for a variety of reasons. The complexity of water consumption and management behavior is highlighted in several studies (e.g., [28,29]). Farmers' experience with climate impacts and their concerns about water availability are in fact mediated by local facilities, services, and institutions such as infrastructure, irrigation facilities, water management mechanisms, irrigation water costs policy, etc. Such facilities, services, and institutions may induce farmers to ignore local climate constraints such as water shortage. Water consumption and management behaviors are complex, dynamic, and systemic in nature and are often built on habits [28,29] and socio-political background, making them difficult to change.

3. The Local Context

The island of Sardinia in the Western Mediterranean Basin has faced a persistent water emergency. About 80% of the productive and domestic water supply relies on a number of reservoirs built mainly in the 20th century, and around 20% comes from wells. According to Bauer et al. (2011) [30], the island has experienced a serious drop in rainfall by some 50%–60% over the last 20 years that caused a water crisis. This situation led to the declaration of a state water emergency (DPCM 28 June 1995) in 1995, extended to 31 December 2003 (DPCM 13 December 2001). On the basis of water availability and inhabitants in the year 2000, the estimated available volume of water per resident per year is around 260 m^3 (Ex-ante environmental assessment–POR Sardegna 2000–2006), which is far lower than the threshold of 1000 m^3 representing a chronic water scarcity threshold according to the Falkenmark water stress indexing. This situation poses a severe shortage of water for domestic consumption, agricultural irrigation, animal husbandry, industry, and other economic activities. The index value for Sardinia is, in fact, similar to those for some areas of North Africa and the Middle East, but much lower than those for Algeria (730), Tunisia (450), and Syria (550) [31]. The severe problem of water scarcity in Sardinia is not just related to weather and climate constraints but also to mismanagement and the infrastructure situation [31]. The water supply of Sardinia is organized in a multi-sectorial system, with several levels and overlapping roles among public administrations. This system consists of a set of primary facilities that, directly or indirectly, provide civil users (drinking water), irrigation, industrial and environmental, as well as multi-uses (Regional Law 19/2006). These facilities include dams, spillways, aqueducts, canals, water pumping stations, and hydroelectric power stations. They belong to the regional governments, which is also the owner of all the concessions for public water, or certificates to derive the resources from the system itself. Instead, the management of the dams is carried out by ENAS (Ente Acque della Sardegna), which allocates the available water by distributing it equally between the various users. ENAS also equalizes its pricing policy, which is based on the ability of the users to pay: therefore, agriculture is requested to contribute to covering the operating costs of the provision of the raw water, with payments that are proportionately lower than the civil sector and industry. The raw water is distributed to end users by sectorial agencies by means of a secondary network of canals and pipelines: specifically, Consortia among farmers (CBI) are water use associations in charge of operating the secondary network for the irrigation water. Farms have to pay the CBI irrigation contributions to cover its operating costs.

Our study was conducted in Oristano, in Central-Western Sardinia, Italy. Oristano is a predominantly agricultural region and agriculture is the dominant livelihood of the local population. In 1982 the total agricultural land was 67% of the total area of the province; in 2000 it had fallen to 51%, and in 2010 it increased again to 55% (Italian National Institute of Statistics). The area was chosen as a study area for its diverse agricultural activities (e.g., irrigated cropping and intensive livestock systems, rainfed grassland and extensive livestock systems, intensive horticulture and cereal production), and for its representativeness of the Western Mediterranean region. Arborea, one of the municipalities of the province of Oristano, has become one of the most productive agricultural sites in Sardinia, and the productivity of its dairy cattle system is considered one of the highest in Europe [32]. Arborea has been designated as the only Nitrate Vulnerable Zone (NVZ) in Sardinia, which generated new spaces for research and development (e.g., [33,34]). The province also includes 62 km^2 of wetlands (lagoons), 29 km^2 of lakes, and 104 km of rivers. The climate of the study area is typical Mediterranean, with some 70% of the total annual rainfall (572 mm) concentrated between October and March, an average annual temperature of 16.1 °C, winter temperatures rarely below 0 °C [35], and an aridity index (annual rainfall/annual reference evapotranspiration) of 0.52. Under the current climatic conditions, average actual crop evapotranspiration ranges from 392 mm·$year^{-1}$ in the rainfed grassland to 1176 mm·$year^{-1}$ in the irrigated alfalfa. Average irrigation inputs range from 540 mm·$year^{-1}$ in the Italian ryegrass + silage maize double cropping system to 630 mm·$year^{-1}$ in alfalfa. The average annual water surplus (runoff + percolation) ranges from 93 mm·$year^{-1}$ in the rainfed grassland to 287 mm·$year^{-1}$ in the irrigated Italian ryegrass-silage maize double cropping system. The most demanding crop in terms of irrigation is paddy rice with an average irrigation input of 1080 mm·$year^{-1}$. The trend of climate variability in the last 50 years of the area was described by Nguyen et al. [15].

4. Research Methods

The research was carried out with integrating various approaches and methods. Firstly, semi-structured interviews and a paper handout survey were conducted in 2012–2013. Twenty-five farmers were interviewed to understand farmers' perceptions of climate variability and climate impacts in the last 30 years. Interviewed farmers were all male (official statistics report that only 23.9% of Sardinian farms are registered to female farmers, but many of these are in fact conducted by male farmers [36]), aged between 35 and 55 years. Their names were randomly selected from the farms' list provided by a Coldiretti Oristano Farmer's Union, which includes only family-run farms, and only male members were delegated to respond to our interviews. A subsequent questionnaire survey was designed based on statements regarding perceived indicators coded from the outcomes of the semi-structured interviews and implemented in 2013. The questionnaire survey was designed to evaluate the agreement levels of farmers' perception of climate variability (1—strongly disagree, 2—disagree, 3—uncertain, 4—agree, 5—strongly agree); their experiences and beliefs on climate change and water availability for agriculture (1—Yes, 2—Maybe/not sure, 3—No, 4—Don't know). One hundred eighty anonymous questionnaires were kept at the offices of Confagricoltura and CIA Farmers' Unions in the Oristano province. Farmers visiting these organization offices for collecting farm inputs, product marketing, and technical and administrative assistance were randomly asked to respond to the questionnaire. The total number of respondents is 138 (20% dairy cattle farmers, 30% shepherds, 29% horticulturists, 16% rice producers, and 5% others); 82% of them use water supplied from CBI while 18% use water from wells. The response rate was 77% (n = 138/180). The majority is male (93%) and the average age is 49.

Secondly, present and future climate trends were also analyzed using a weather observation dataset from 1959 to 2012 collected at the Santa Lucia weather station (Zeddiani, OR, 39°56′ N, 8°41′ E, 15 m a.s.l.). The future climate scenarios were developed using the calibrated output of the Regional Atmospheric Modeling System (RAMS) [37] and the WXGEN weather generator [38]. The non-hydrostatic numerical model RAMS is forced by the ECHAM 5.4 atmospheric global model, managed by the Centro Euro Mediterraneo per i Cambiamenti Climatici (CMCC), for the A1B emission scenario in the framework of CIRCE EU-Project. Two 11-year time series were computed representing a contemporary climate period 2000–2010 and a near-future one, 2020–2030. The choice of a decadal time interval and near future perspective is related to the ultimate goal of this research, supporting adaptive policies in agricultural water resources management, which rarely have a long-term perspective, and the assumption that farmers' and policymakers' choices are made in terms of the current available technology and socioeconomic context. This choice reduces the natural climate variability representativeness by focusing on a short near-future period where emission scenarios are similar. Each 11-year weather dataset was transformed into a 150-year daily series, In order to improve the statistical representativeness of the 11-year daily weather time series, the summary statistics of each RAMS scenario were used as input to the WXGEN weather generator [39] to compute a set of synthetic time series of 150 years of daily weather data, which were then used to run crop model simulations (Table 1). The present and near-future climate scenarios were the most important drivers for simulating the irrigation needs of the crops.

Table 1. Representative values for land use (%), irrigation needs (seeding to harvest in annual crops or annual values in alfalfa) under observed climate, and percentage changes of irrigation requirements under near-future climate vs. present climate (%Δ).

Crop System	Land Use (%)	Irrigation Needs (mm)	Percentage Changes Future Climate vs. Present (%Δ)
Italian ryegrass	16	114	+40
Silage maize	30	429	−4
Alfalfa	13	516–639	+5
Rice	15	664	−1

Thirdly, the two crop models, EPIC–Environmental Policy Integrated Climate, v 0810; [39] and DSSAT-Decision Support System for Agrotechnology Transfer v 4.6 [40,41] were used to estimate the irrigation needs of the four crops (i.e., ryegrass, maize, alfalfa, and rice) that in the last 10 year, cover 75% of the actually irrigated area in the province served by the consortium (Figure 1). EPIC was widely validated and used for several purposes ranging from the simulation of crop yields [42,43] to more complex uses like climate change impacts on crop yield and erosion [42,44,45]. DSSAT was used to determine optimum crop management practices (including cultivar, fertilizer, water, and tillage), precision agriculture, climate change and variability, long-term sustainability, environmental pollution, and genomics [40,41]. We applied EPIC to simulate alfalfa and a silage maize-Italian ryegrass double cropping system. We calibrated EPIC based on local crop datasets, soil and weather from field trials, and business-as-usual cropping system management from interviews with farmers in the study area. The impact of climate change on the water balance of the cropping systems was also estimated using the EPIC model: actual evapo-transpiration was calculated from the Penman-Monteith equation considering the actual crop management. Considering that the crop yield for annual crops is estimated by EPIC using the harvest index concept, which is adjusted throughout the growing season according to growth constraints, and that the physiological responses to water stress are considered with direct impact on harvest index and canopy growth, several simulations with different managements were carried out. In the simulations, crop irrigation requirements were calculated taking into account actual precipitation and groundwater table uptake. By performing simulations eliminating the water stress using the EPIC automatic irrigation option we were able to quantify the irrigation volumes required to ensure the observed yields.

We applied DSSAT to simulate the water balance of rice. We obtained datasets for rice from surveys, interviews, observations, sample analysis, and data systematically collected by private farms. The cultivar coefficients of the crops for DSSAT were estimated with the Genetic Coefficient Estimator [46] based on long-term data obtained from private farms. The coefficients of species and ecotype were left unchanged [47].

Finally, the impact of CC in altering crop irrigation requirements and production yields in the near-future scenario was assessed by transforming the 150 occurrences generated by the crop models into probability distribution functions, which produced the inputs for a Discrete Stochastic Programming (DSP) economic model [47]. The DSP model used is described in Appendix A.

This economic model simulates the management decisions of farmers and the resulting income under the condition of uncertainty generated by the weather variability that is typical of the climatic scenario in which farmers operate. This is done firstly under the current climate, then for the future.

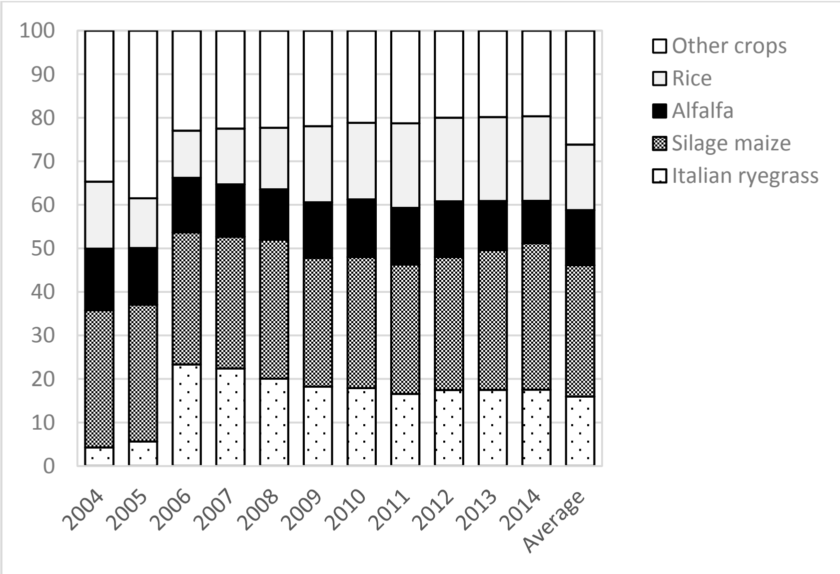


Figure 1. Percentage breakdown by crop type of the irrigated water areas assigned by the Oristanese CBI. Italian ryegrass is grown as an irrigated hay crop integrated into a double cropping system in the same areas occupied by silage maize.

The calibration and validation of the DSP model concerned the use of land, water, and other resources as observed in the current scenario, and employed the methodology of positive mathematical programming (PMP). This procedure assumes that farmers have full knowledge of the current climate variability and its effects on agricultural production. In other words, the assumption is that farmers know the present probability distribution of the possible, various levels of irrigation needs, and the yields of the crops. Once calibrated to the current climate, the DSP model is used to simulate the possible management choices of the farmers for the climate of the future. For this purpose, the production data generated by the agronomic models under the climatic conditions simulated for the future are replaced to by data from the current scenario. In particular, the future *states of nature* of the different agro-climatic variables are considered, namely their representative values and probabilities. The comparison between the productive and income outcomes obtained the DSP model under the current and future climate scenarios indicate the capability of these farming system (with their endowment of resources and technologies, and relations with the market) to adapt to climate change (with a new use of technologies, land, and, in general, agricultural resources). We compare these adaptive solutions with the perceptions on climate change detected by interviewing farmers, to check the consistency between their expectations of climate change and possible reactions to it, and the adaptation responses that the economic model attributes to them under the future climate scenario.

Clearly, until the new future scenario occurs, technological, structural, political, and market changes will all take place, allowing different adaptation options. However, the simulation of farming under a future scenario, and its comparison with the current outcome is useful because it indicates the crop and farming systems that may be more subject to stress, as well as the directions in which they can change. This comparison is also useful because it is not certain that the changes that farmers perceive are actually important from a climate point of view and, above all, that can have a major impact on the use of agricultural resources and, therefore, on farm incomes. The analysis of the economic model's results in the future scenario may help in assessing these aspects.

5. Results

5.1. Farmers' Perceptions of Climate Variability

Farmers have perceived changes in climate variability over time in Oristano province. Most of the interviewed and surveyed farmers perceived that temperature had increased over time and there had been changes in annual season calendars, while only a minority (less than 20%, $n = 24$) perceived that rainfall had decreased in the last few decades. A large number of farmers tended to be unsure of or disagree with decreased rainfall patterns. Farmers did not have homogenous perceptions on drought status: 46% ($n = 63$) of surveyed farmers perceived that drought had increased in its intensity and frequency, 27% ($n = 37$) were uncertain, and 26% ($n = 36$) disagreed with this phenomenon (Figure 2).

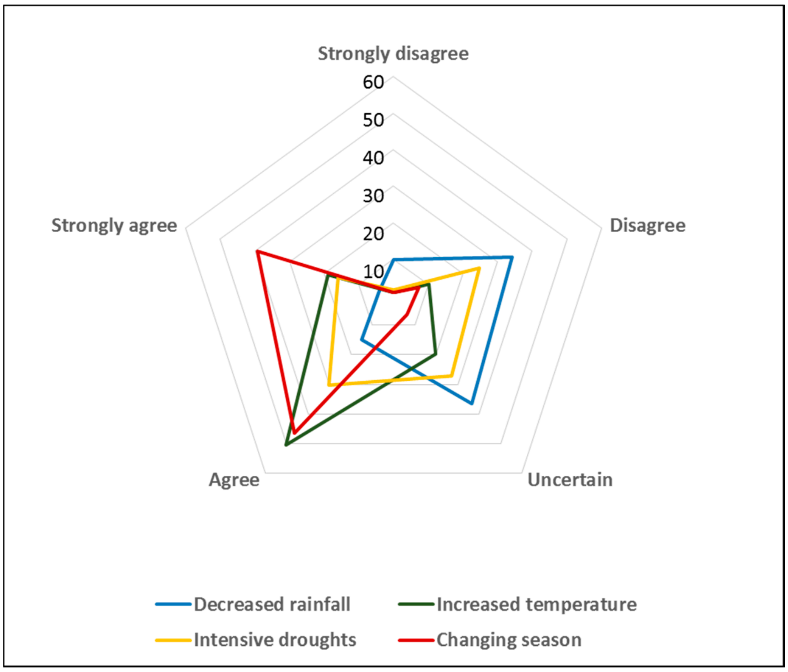


Figure 2. Farmers' perceptions of climate variability quantified by % response for five levels of agreement: Strongly disagree, Disagree, Uncertain, Agree, Strongly agree (Likert type).

5.2. Farmers' Perceptions of Climate Impacts

Farmers in the Oristano province perceived the potential impacts of climate change, mainly on farming systems and water resources (Figure 3). Most interviewed and surveyed farmers (some 65%–85%) felt that climate impacts induced an increase in plant and animal diseases; as one farmer remarked, "*I heard that climate change induces increased temperature that leads to negative impacts on animal and crop management. Farmers in many other countries are facing problems with animal health, especially in summer, and we are in the same situation*." Consequently, a large number of farmers (more than 65%) agreed/strongly agreed that climate change has affected their production/yield. Some interviewed farmers also expressed a belief that reduction of plant growth and loss of biodiversity were among climate impacts: "*For me the environment has been changed . . . What I saw when I was 5 years old nowadays I don't see anymore, for example, some birds have disappeared, as well as some rabbits or other wild animals, insects, like butterflies...*". However, the results of the questionnaire survey showed that half of surveyed farmers were uncertain and disagreed with the loss of biodiversity and 12% ($n = 17$) did not answer the question.

Farmers have also perceived changes in ground and surface water availability. The majority of farmers (53%, $n = 73$) agreed that groundwater had decreased overtime, while approximately

23% (n = 32) were unsure and 13% (n = 18) disagreed with this issue. A large number of farmers (43%, n = 61) also perceived that surface water availability had also decreased, while 31% (n = 43) were uncertain and 17% (n = 23%) tended to disagree about the status of surface water availability overtime. Yet despite some climate impacts on ground and surface water availability that farmers perceived, a large number of farmers (39%, n = 54) disagreed that there has been a reduction of water in reservoirs, while 25% (n = 24) were unsure and only 25% (n = 24) agreed.

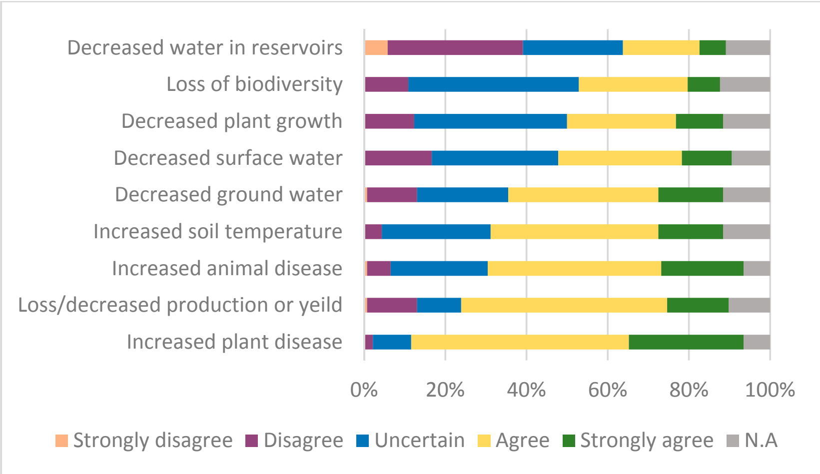
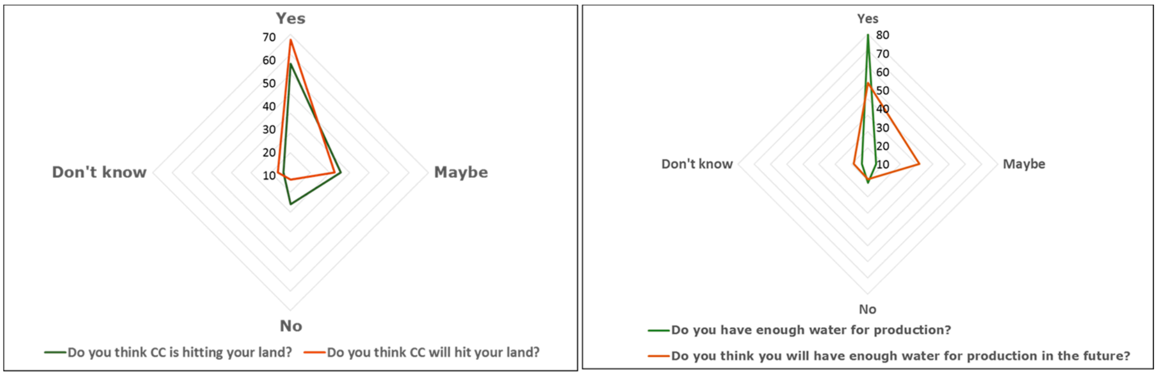


Figure 3. Farmers' perception of climate impacts. Statements are ranked in ascending order by total percentage of "Agree" and "Strongly agree" (Likert type).

5.3. Farmers' Beliefs about Climate Change and Water Availability

As a result of perceiving climate variability in Oristano, farmers hold quite homogenous views related to climate change (Figure 4a). The majority of farmers responded that climate change is happening (55%, n = 76) and will happen (67%, n = 93) in their area. One farmer expressed: "*Some things have changed in our territory but we feel a bit less than what is talked about globally*." Another additional farmer remarked, "*I think climate change will happen in this area but after several decades in the future, not in the short term*." Perhaps in part because of the uncertainty and complexity of climate change, the remaining surveyed farmers (22%–25%) were unsure whether climate change is hitting/will hit their area. However, a still small number of farmers do not believe that (4%–15%) or do not know if (4%–7%) climate change is hitting/will hit their land. One farmer said, "*Climate change? I do not believe much . . . It is a natural process I think*." Or, as another farmer noted, "*I do not think about this problem. I can still keep the current production system until something will happen in reality. Climate change is a worldwide problem that cannot be addressed at the local level*."

During the interview, it was noted that farmers had not experienced a problem with water availability for agriculture; as one farmer explained, "*I have always had available water for production; there are irrigation systems and dams . . .* ." This is proved by the results of the questionnaire survey: 80% (n = 110) of farmers confirmed that they had enough water for production (Figure 4b). Farmers seemed worried about the risks of flooding because of excessive rainstorms rather than water shortage due to droughts. For this reason, many farmers quoted it as a serious problem that they have been facing; as one said, "*Thanks to the dam, there is availability of water for a long-term adaptation. It is excessive rain that can be a problem, more difficult to adapt to*." Consistent with the interview outcomes, the questionnaires also highlighted that farmers do not perceive that water availability will be a major problem in the future: 50% (n = 69) of them believed that they will have enough water for production in the future, while approximately 32% (n = 44) were uncertain about future water availability. Less than 10% (n = 13) believed they will not have enough water for farming purposes in the future and about 8% (n = 12) did not know.



(a) Farmers' beliefs about climate change (b)Farmers' beliefs about water availability

Figure 4. (**a**) Farmers' beliefs about climate change; (**b**) farmers' experience and belief about water availability, quantified by % responses for four levels: Yes, Maybe, No, I don't know.

5.4. Present and Future Climatic Scenarios

In the near-future scenarios, both minimum and maximum seasonal mean temperatures are expected to increase in all seasons, with a stronger signal in the summer. Mean value changes of expected seasonal precipitation are negative and weaker in winter and stronger in spring (−33%), while weak positive or absent changes are expected for summer and fall, respectively (+80% in August, +23% in October) (Figure 5).

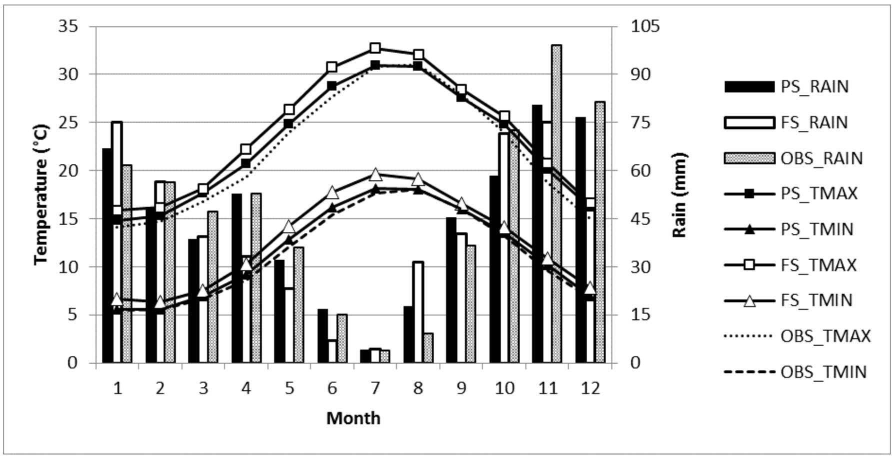


Figure 5. Observed and synthetic generated climate values for 150 years: average values of maximum and minimum temperatures (TMAX, TMIN) and precipitation (RAIN) for current and future scenarios (PS, FS).

5.5. Present and Future Scenarios of Crop Irrigation Needs

The irrigation volume for Italian ryegrass, which is only supplied in relation to actual water requirements in spring before the mid-May hay cut, increased by about 45 mm under FS because of the expected reduction of precipitation in spring. The irrigation volume of silage maize under FS slightly decreased because of the shortening of the maize cycle due to increased summer temperatures. On the contrary, alfalfa and rice irrigation needs to be increased because of the increased summer temperatures (Table 1).

Under FS, the total annual rainfall slightly decreased (−7%) and the total annual evapotranspiration of the irrigated crops increased by between +5% (alfalfa) and +7% (Italian ryegrass + silage maize). In the case of maize in particular, the effects of increased temperature on evapotranspiration were offset by the shortening of the crop cycle (−12 days). The changes in the annual water surplus (runoff + percolation) under FS ranged from −12% in alfalfa to +3% in the Italian ryegrass-silage maize double cropping system. Also in the case of rice, the impact of FS on crop water requirements, related to increased mean temperature, was offset by the shortening of the crop cycle (−12 days), leading to no significant differences in terms of net irrigation needs, which are supplied with the flooding irrigation practice in paddy fields (on average some 1080 mm·year^{-1} in Oristano), where water also has the role of buffering temperature fluctuations and hence runoff represents some 50% of the total water balance.

5.6. Baseline and Future Scenarios of Economic Impacts and Land-Use Changes for Various Farming Systems

The economic model results define the use of agricultural resources (land, water, and labor) and the income from them in the current climate scenario and in the future scenario. The next tables present the DSP model results in the current scenario and the relative percentage changes in the future scenario. These results regard the totality of specialized rice farms and dairy cattle. The latter are divided into two groups, where group A is the largest and relates to the best-performing farms in terms of management. The impact on economic results (Table 2) shows that the net income under the future climate scenario is forecast to increase in rice farms (9.3%) and decrease in the two types of dairy cattle (5.1% and 5.9%, respectively).

Table 2. Economic results for the baseline and near-future scenario, absolute values (000 €), and percentage changes [47].

	Present (000 €)				**Near Future (% Changes over Present)**			
	Rice	**Cattle A**	**Cattle B**	**Total Area**	**Rice**	**Cattle A**	**Cattle B**	**Total Area**
Total revenue	9,511	59,194	16,492	85,197	4.1	−1.3	−0.9	−0.6
Crops	9,511	252	156	9,919	4.1	11.5	57.6	5.1
Animals	0	58,942	16,336	75,278	0.0	−1.3	−1.4	−1.3
Variable costs	7,013	33,119	9,124	49,257	−0.2	1.8	2.9	1.7
Feeds	0	15,689	3,319	19,008	-	−5.2	−6.4	−5.4
Gross margin	5,294	35,509	9,941	50,744	7.6	−3.8	−4.1	−2.6
Net income	4,317	26,355	6,825	37,498	9.3	−5.1	−5.9	−3.6

Rice farms had an increase in revenue. This is due to the rise in crop yields, and related sales, simulated by DSSAT as generated by the fertilization effect of the higher atmospheric concentration of CO_2 under the future climate scenario. However, this increment does not generate an expansion of cultivated area, which remains substantially unchanged as it is constrained by the specific suitability of the available soils (Table 3).

Table 3. Land use changes for the baseline and near future scenarios, absolute values (hectares), and percentage changes *.

	Present (Hectares)				**Near Future (% Changes over Present)**			
	Rice	**Cattle A**	**Cattle B**	**Total Area**	**Rice**	**Cattle A**	**Cattle B**	**Total Area**
alfalfa	25	528	276	829	−15.4	−77.6	−53.4	−67.7
corn silage total	0	3215	1050	4265	-	12.9	12.4	12.8
standard hybrid	0	3215	1050	4265	-	−22.2	−21.9	−22.1
hybrid with shorter cycle	0	0	0	0	-	*1129*	*360*	*1489*
ryegrass	0	2198	720	2917	-	9.2	12.4	10.0
rice	2422	0	0	2422	0.3	-	-	0.3
other crops	653	413	84	1150	−0.6	1.7	51.2	4.0

Note: * Absolute values for *hybrid at shorter cycle* in the *Near Future* scenario.

Revenues of dairy cattle farms decreased mainly because of the reduction of milk production and worsening of its quality levels as a consequence of the increase in temperature and humidity in the summer months forecast for the future scenario. Also, fodder production and purchase of feeds, and the related costs, are expected to change. Silage maize production increases, especially that of long-cycle hybrids, which are better adapted to the new climatic conditions. This allows farms to reduce purchases of feeds. However, changes in feed requirements and fodder production resulted in negative income because of the net increase of the variable costs. Also, the cultivation area of alfalfa is expected to decrease, while ryegrass production increased (Table 3).

6. Discussion

6.1. Symmetries and Asymmetries between Farmers' Perceptions and Present and Future Climate Scenarios

The research findings showed that most farmers perceived changes in the climate; however, their perceptions are both consistent and inconsistent with present and future climatic scenarios as envisaged by the climatic analysis. The majority of farmers felt that temperature has increased in the last decades and this is in line with what is observed for present and future temperature trends. Both min and max T were observed to increase and this increment is also expected to occur in all seasons with a stronger signal in the summer. This is also confirmed by the results of the economic model that simulated an increase in revenue for rice and a decrease in revenue for dairy cattle farms in the summer months. In the case of rice, the expected rise in crop yields was simulated as a consequence of the fertilization effect of the higher atmospheric concentration of CO_2, while the reduction of cow milk production was generated by the summer increase of temperature and humidity [47]. Increased temperature would seem easy for farmers to feel as there is a close link between haptic perception and human senses [48] and experiential processing often involves feelings and simple heuristics [49]. Perceived temperature is classified into two opposite categories of pleasant and unpleasant; most farmers strongly expressed their experience with hotter weather based on their personal feeling of unpleasantness. Moreover, perception is always associated with an experience of production losses; indeed, as a result, farmers perceived that there had been increased animal and plant diseases in the last few decades because of hotter weather/heat weaves.

While changing season is the first perceived phenomenon on which most farmers strongly agreed, perceptions about the precipitation pattern were more uncertain. Experience of changes in seasonal calendars of agricultural operations and of changes in crop performance was used by farmers as a perceived indicator of changes in climate, while precipitation itself is not easy to perceive by human senses without an appropriate instrument. Although different perceptions of drought were seen between irrigation (e.g., intensive dairy cattle farmers) and rainfed farmers (e.g., extensive dairy sheep farmers) due to different characteristics of farming systems, farming calendars, irrigation practices, and technology investments [15], more than 80% of surveyed farmers disagreed with decreased rainfall pattern (44%) or were uncertain about this phenomenon (37%). The simulated present and future precipitation scenarios showed that rainfall tends to decrease in winter and spring while it remains unchanged or slightly increases in summer and autumn. Farmers did not accurately perceive or were uncertain about future rainfall patterns and, actually, the rainfall scenarios do not provide a clear trend during the irrigation season, especially since most farming activities are irrigated in the study area. Their perceptions of rainfall differed to those of farmers reported in other studies (e.g., [50,51]) whose farming mainly relies on rain water, in which farming calendars/practices are to be adjusted to better cope with perceived changes in rainfall. In addition, farmers remembered more "unexpected events" [15,24] and production losses in the most recent years [52,53], often confusing weather with climate [15]. The observed climate data showed that there has been an increase in rainfall during summer/autumn in the last 10 years. Farmers in this area traditionally experience dry and very dry weather in summer and this could have influenced their perception of precipitation pattern when they observed an increased rain frequency outside of the rainy season. Moreover, as expressed by many farmers during the interviews, the increased precipitation frequency in summers in the last few years has caused losses and/or difficulties in managing animals and crops during such unexpected events.

6.2. Factors Influencing Farmers' Beliefs and Concerns about Water Availability

Unclear rainfall trends and a lack of or limited experience with water shortage for irrigation (e.g., 80% of surveyed farmers agreed they have enough water for production) in the last decades have led to inconsistency in famers' responses. A high number of farmers (44%) disagreed with a decreased rainfall pattern, but a high number of farmers (46%) tended to agree that drought occurrence had increased. Although farmers perceived changes in climate and their impacts on their farming systems and they believed climate change is happening and/or will happen in the future, a majority of them believed they will have water available for irrigation in the future. Farmers' perceptions and experiences of climate change were formed based on their beliefs, knowledge, and experiences [54], but these perceptions and experiences also shape and justify their beliefs. While the majority of farmers felt that ground and surface water availability has decreased, a large number of farmers did not feel a reduction in water volumes in the reservoirs overtime. This justifies their belief about future sufficient water availability. Farmers' perceptions and experiences of water availability are, however, in contrast to the actual water demand–supply scenarios in Sardinia. In Sardinia, the water demand is some 1160 $mm^3/year^{-1}$, of which some 807 mm^3 is only for irrigation. Irrigation accounts for 55%–85% of total water demand in all agricultural areas of Sardinia. Comparing water supply and demand, a water supply deficit of some 547 mm^3/year is expected, about half of the total requirement. Despite the fact that Sardinia is faced with persistent water scarcity and there is a high deficit in the water demand–supply balance, farmers in the study area are more worried about flooding than water shortages. Similar to the results of the consumer behavior survey on Water Use and Water Conservation in the United Kingdom by Christensen and Kowalski (2006) [55], the majority of farmers in our case believed that they have enough water at present and will have enough water for production in the future. They do not think water shortage is a serious problem in their area. This is also a consequence of the fact that on the island only a small proportion (some 20%) of the area that can be potentially irrigated is actually irrigated for a number of reasons that are not the object of this paper. The experience of unusually frequent precipitation during summers in recent years led farmers to believe that "the recent weather is more representative of a longer-term period than it really is" ([56], p. 2). Many interviews also revealed farmers' confidence in solving/overcoming droughts/water shortages through efficient irrigation systems. In fact, infrastructures like irrigation systems may serve as important facilities to adapt to foreseen increased water deficits in the future, thereby strongly influencing farmers' perceptions.

The increased temperature scenarios may induce an increased demand for irrigation of crops because of heat stress. The results of crop model simulations also demonstrated that there will be an increase of irrigation needs in all studied crops (except maize, unless later hybrids will be used to counterbalance the crop cycle reduction because of the higher temperature) in future scenarios. In the context of water demand–supply deficit in Sardinia, this situation raises serious concerns about future water availability for irrigation in the region. However, the research findings showed contradictions between water demand–supply/crop irrigation need scenarios and farmers' beliefs about water availability, which is mediated by social and institutional lenses. The lack of information/awareness about the potential water scarcity in Sardinia and the presence of efficient irrigation systems led many farmers to believe that they would not face a serious problem of water scarcity in the future. Moreover, the cost for irrigation water applied by the local CBI, which is currently set by a fixed estimated volume per crop on a per unit area basis, led to farmers' habit of relying on unlimited use of irrigation water. Knowledge, information, and facilities available to individuals as well as the perceived will of institutional bodies are determinants of engagement with environmental issues [57]. Many previous studies on the topic have also highlighted several incentives and barriers to engaging with environmental issues including habitual behavior [58], knowledge, information, and institutional [57] and situational variables [59]. Beliefs about water availability may lead to unchanged water saving behavior in farmers. If they recognized their responsibility for efficient water management but water authorities were not perceived to be playing their part in regulating water management policies (including pricing policies), it would be difficult to change their behaviors until a perceptible water crisis occurred. However, while some adaptive behaviors can be adopted year by year by changing some agricultural practices when annual crops are involved (e.g., change the variety or sowing date), others may require substantial early investment [60] (e.g., plant breeding for the production of new varieties, investments in agricultural education and extension, new infrastructure and equipment to improve irrigation or cooling facilities for livestock) to prevent farm profitability from being challenged for several consecutive years by the increasing frequency of unfavorable events (e.g., summer heat waves) before farmers have the economic capacity to respond in a timely manner. Adaptive management requires not only the involvement of stakeholders but also decision-makers and managers who have to be well informed and aware of the environmental risks [61]. Foresight mechanisms need to be set up by water managers for increasing the awareness of water users about future water scarcity, in order to encourage voluntary behaviors towards a more efficient and conservative use of water. However, managers, in some cases, showed a low perception of environmental risks (e.g., the findings of Petrosillo et al. [61] on environmental risk perceptions of tourist harbor managers in the Province of Lecce, Apulia Region, Italy). While further substantial investments in irrigation infrastructures are considered a prerequisite for climate change adaptation, our results are consistent with other research findings showing that effective adaptation pathways can emerge through investment in new social learning spaces and multi-actor platforms involving water managers and users at different levels, in order to enhance the perception of climate change and improve the ability to respond in a timely and concerted way.

7. Conclusions and Implications

Failure to consider farmers' perceptions and key drivers of climate impact beliefs as well as adaptation attitudes would lead to ineffective and inefficient development of sustainable adaptive strategies. The research findings showed that although farmers perceived changes in climate and the climatic and crop models simulated clear increases in the irrigation needs of most crops as a consequence of increased temperature and decreased precipitation, farmers in our case study are convinced that they have and will have enough irrigation water for agriculture, despite the fact that they operate in a regional context of persistent water scarcity. We also found that (i) farmers' perceptions and experiences of climate change were based on their beliefs, knowledge, and experiences of climate change and its impacts, but these perceptions and experiences also shape and justify their beliefs about water availability; and (ii) farmers' experience with and concerns about water availability are mediated by local facilities such as infrastructure, irrigation systems, and water management policy.

Increasing water legislation focus, at both European and national levels, is being placed on saving water. Therefore, water use efficiency in agriculture is considered the top priority in water management policies and practices. Understanding farmers' perceptions of climate impacts and beliefs about water availability can help policymakers to understand farmers' behavior in response to the impacts of climatic pressures, especially the impacts of droughts on farming systems and water scarcity, and to take action to mitigate and adapt to future changes. Investment in irrigation infrastructure may help farmers overcome water constraints, while understanding the factors that influence farmers' perceptions and beliefs can help integrate communication into adaptation research/policies and enhance the dissemination of scientific knowledge at the farm level. Our study suggests the need for (i) irrigation management policies that take into account farmers' perceptions in order to enhance virtuous behaviors and increase irrigation water use efficiency; and (ii) designing and implementing new learning spaces among multiple actors (including water managers and users, researchers, and policymakers) to improve the understanding of climate change issues expected in the near future and support effective responses at the farm level.

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Appendix A. The DSP Model Specification

The mathematical representation of the DSP model used in this study can be compactly defined as follows:

$$\max_{X_1, XR_{n_s}} z = GI\ X_1 - \sum_{n=2}^{N} \sum_{s=1}^{S} P_s\ Cr\ XR_{n_s} + Pm\ Qm\ , \tag{A1}$$

subject to:

$$A\ X_1 \leq B \tag{A2}$$

$$A_s X_1 \leq B + \sum_{n=2}^{N} XR_{n_s}\ \forall\ s \tag{A3}$$

$$NT\ Y_s X_1 + \sum_{n=2}^{N} XR_{n_s} \geq R\ \forall\ s \tag{A4}$$

$$X_1 \geq 0\ and\ XR_{n_s} \geq 0\ \forall\ s, \tag{A5}$$

where 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 ($n = 1$); XR_{n_s} are corrective actions performed in the subsequent stages ($n = 2, \ldots, N$) on the actual occurrence of one of the states. These actions modify the available additional resources, which have a cost (Cr). Equation (A1) is the objective function (z) that sums up the different components, including the gross margins (GI) of the activities chosen in the first stage (X_1) andthe 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 up over the N stages. Finally, the objective function sums up the revenues of milk, based on the price (Pm) and total quantity (Qm) obtained under present and future climate scenarios. (The mathematical notation of the model explicitly considers the effects of present and future climate change on cow milk revenues because they are not considered by the sections dedicated to the allocation of land, as it does for crops to sale (rice, wheat and barley). The effects of the climate 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 the climate impacts on it.) Constraints (A2) refer to land and labor resources: A is the matrix of technical constraints and B is the quantity of available resources. Constraints (A3) refer to the water resources 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 state (s). Constraints (A4) refer to animal feeding: NT 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 choice involve corrective actions, XR_{n_s}, in stages (n) for each state (s).

The model was calibrated to the reference year 2010 with the PMP approach of Röhmand Dabbert (2003) that allows for modeling the choices between technically similar crops, whose mutual substitution elasticity is greater than that relating to other crops [62]. The calibration involved land allocation among crops decided in the first stage.

The representative values and probabilities of the states of nature for the various crop variables (yields and water requirements) were estimated by executing EPIC, DSSAT, and livestock models on the climate data of the synthetic 150 years. The outcomes were used to estimate the PDFs 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 (ETN) of the future climate with respect to the present. All the PDFs were obtained with a maximum likelihood estimator. Chi-square tests were applied to identify the function that best approximates the dataset. Finally, the range of each PDF was divided into three 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.

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