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# **An evaluation of the economic impact of Climate Change through a three-stages Discrete Stochastic Programming model**

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# **An evaluation of the economic impact of Climate Change through a three-stages Discrete Stochastic Programming model<sup>1</sup>**

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## **Abstract:**

The climate change in the agricultural sector acting on multiple weather variables at different times of the various crop cycles. In several cases by changing the mean level of variables (rainfall, temperature, etc..), in other cases by changing the distribution of events. This work provides an evaluation of the economic impact due to changes in multiple events, and to the associated uncertainty. For this reason, a classical two-stage stochastic programming model was extended into a three-stages model. The model is specified for an area of Sardinia, and examines the impact of climate change on rainfall and hence on the availability of water for agriculture, and on maximum temperatures and, therefore, on the requirements of some irrigated crops relevant to the agricultural economy of the area. The effect of climate change is obtained by comparing the results of scenarios that represent the climatic conditions in the current situation and in the future, obtained by projecting to 2015 the climate trends of the last fifty years. The results show that the agricultural sector of the area adapts itself with a low cost by use of land and cultural practices. This cost, however, is very high for some farms that suffer a significant reduction of the income. There is also an increase of the use of natural resources, in particularly groundwater. The economic impact of these changes is due primarily to the decreased of water availability in the future. The availability of water becomes the crucial factor to adapting to climate change, because the effects of temperature can be compensated by increased the use of water resources.

**Keywords:** Discrete Stochastic Programming Model, climate change, water availability, irrigation requirements.

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## 1. Introduction

This work provides an evaluation of the economic impact of Climate Change (CC) on rainfall and maximum temperatures that in the literature are considered as the main climate components (IPCC, 2007, Solomon et al., 2007). This analysis concerns the effects that these two components have in the variation of use of agricultural land, of inputs (water, work, etc..) and of the income of agricultural sector in a specific area. In particular, the possible impact of CC on precipitation and, consequently on the availability of water for agriculture, and maximum temperatures and, therefore, and irrigation requirement of the crops were examined.

The contribution of this analysis is twofold. The first is methodological, because a three-stages Discrete Stochastic Programming (DSP) model is proposed to represent two climate components and therefore two elements of uncertainty. In this way we try to improve the analysis of economic impacts of CC that in the literature represent the climatic effects of a single component (Bazzani and Scardigno, 2009, Dono and Mazzapicchio, 2010 (a) and (b), Dono and Mazzapicchio, 2009).

The second contribution concerns the interdisciplinarity of the work, in which the economic analysis has been linked by an analysis developed with the agronomic model Environmental Policy Integrated Climate (EPIC), which predicts the change of weather variables will affect the needs and culture results. The analysis of the agronomic model was developed by University of Sassari. The analysis of the economic model of three-stage DSP model is developed by researchers the University of Viterbo. These two groups work at the Agrosenari project on the problems of Italian adaptation to climate change ([www.agrosenari.it](http://www.agrosenari.it)).

The analysis concerns an area of north-west of Sardinia where at the beginning of the agrarian season the farmers are uncertain about the availability of irrigation water in the dam, influenced by the autumn-winter rains, and about the irrigation requirements of some crops, influenced by the spring-summer temperatures. The availability of water for irrigation is known by the farmers only at the beginning of irrigation season. The irrigation requirement is an element of uncertainty that is known with certainty only later in the summer. To consider the uncertainty of two climatic events (rainfall and maximum temperatures) at different times a three-stages DSP model was used.

The economic impact is more evident is the reduction, albeit limited, gross margins in dairy herds, while increasing pressure on environmental resources, with a higher extraction of groundwater and increased use of nitrogen fertilizers. These variations depend mainly from reduced future water availability, while isolating the effect of change in irrigation requirements shows that this affects only a small proportion of agriculture land.

In the next section, materials and methods employed, describes the main characteristics of the study, the components concerned and the climatic data used to represent the EPIC model used to define the relationship between temperature and irrigation needs in the territory concerned, the

model PSD with three stages used to simulate the response of agriculture to climate change. The section describes three states of nature and their probabilities of occurrence, starting from the states of nature on water availability and passing those on the needs of irrigated crops. Paragraph four show the results obtained. Commenced from trends in precipitation and maximum temperatures, passing the results of the EPIC model for cultivation, then presents the findings to calculate the probabilities associated with each state of nature, culminating in the results of the model PSD. These will show the first effects more strictly economic, related to income earned throughout the agricultural land and individual business types, then we expose the effects on land use and the various inputs. Paragraph five contains the conclusions.

## **2. Material and methods**

### *2.1. Study area*

The area under consideration is represented by the catchment area of Cuga, located in northwestern Sardinia. Some of the territory is supplied water for irrigation by Reclamation Consortium of Nura, which picks from a dam on Lake Cuga, the total capacity of 84 million m<sup>3</sup>, fed by the river Temo.

The water dam is distributed by the network consortium only in some areas of the Basin, while others do not access this resource and practice predominantly dry farming. In addition, the Consortium provides some areas that fall outside the catchment area of study. The AA area is 34,492 ha, 26,195 ha is in the surface of the basin (Gift et al. 2008).

The consortium conducted covering an area of 21,043 ha and equipped in the last 15 years have allowed an average of 4,000 ha of irrigated farms in about 2900. Until 2001 the payment system of the water used by the Consortium considered hectares put under cultivation (ha / crop). Since 2002, a charge of 0.03 € / m<sup>3</sup> to actual consumption. Companies in the area, in addition to using water from the Consortium, also use water from wells. Water System-Cuga I fear, as well as for irrigation, drinking water is also intended for use by absorbing on average 40% of the total resources available. In years of water scarcity, as the 1995, 2000 and 2002, the Commissioner of the water emergency has favored withdrawals for drinking at the expense of agriculture and farmers, could vary only in the choices already made, have reported significant reductions in income.

### *2.2. Analysis of the main climatic components*

The main components of the climate, particularly precipitation and maximum temperatures can be analyzed using 516 monthly observations from 1961 to 2003 provided by the CRA-CMA for the meteorological station of Alghero airport. Of these series is important to evaluate the long-term evolution for the presence of a trend, as it can be assumed that the time course of the values of these

series, indicating that certain events may be more or less likely, is capable of influence the choices of the farmer. In this study, we estimated a linear trend by the method of least squares.

### 2.3. *Link to maximum temperature and irrigation requirements of the crops*

A number of researchers have demonstrated that crop simulation models are valuable tools for irrigation management. These models can be used to determine irrigation requirements at a farm level (Hoogemboom et al., 1991; Guerra et al., 2002; Nijbroek et al., 2003) as well as at country and state levels (Alexandrov and Hogenboom 1999; Heinemann et al., 2002).

The model Environmental Policy Integrated Climate (EPIC) is a crop simulation model that can be used to assess the impact of weather and management strategies on agricultural production and soil and water resources (Williams et al., 1989; Meinardus et al., 1998). It can simulate a variety of management strategies that include crop rotations, tillage operations, irrigation scheduling, nutrient, and pesticide application rates, and timing. The model has been extensively tested throughout the USA and several other countries (Williams et al., 1989; Bryant et al., 1992; Kiniry et al., 1997).

Most of these studies focused on the evaluation of the biomass and grain yield predictions for various crops when grown under different weather and soil condition and, in some cases, under different levels of irrigation and crop management.

The EPIC model can be subdivided into nine separate components defined as weather, hydrology, erosion, nutrients, soil temperature, plant growth, plant environment control, tillage, and economic budgets (Williams 1990). It is a field-scale model that is designed to simulate drainage areas that are characterized by homogeneous weather, soil, landscape, crop rotation, and management system parameters (Gassman et al., 2005).

The daily data on maximum temperature were acquired by the CRA-CMA that provided us the weather data of the Alghero-airport weather station. We carried out a statistical analysis on the weather dataset for the period 1961-2009. It was divided in two periods of 20 years: 1961-1980 and 1984-2003. The statistical analysis show significant differences in the mean monthly maximum temperature for the two periods considered. We observed the higher increase in temperature in August with an increment of the mean monthly maximum temperature of 2.5 °C from the first to the second period. The lower increase was observed in September (+1.1 °C).

The simulation was carried out using as input data the soil information referred to a typical soil of the study area (Madrau *et al.*, 1981).

Informations about the corn cropping system management and corn silage yield were obtained by direct interviews to the farmers. By this way we simulate the usual management for the considered cropping system in the studied area. The weather data comes from the Alghero-airport weather station. These include information on the daily maximum and minimum temperature and

daily precipitation from the 1951 to the 2009. In order to simulate the climate change, we considered the atmospheric CO<sub>2</sub> concentration also. The CO<sub>2</sub> concentration values were obtained from the NOAA (2010) and they goes from 317.64 ppm in the 1961 to 357.78 ppm in the 2003. In order to reduce the number of days of water stress, the simulation was carried out with a maximum annual irrigation volume allowed of 530 mm and using the automatic irrigation option. Considering the weather data and the crop available water, EPIC estimates the amount of irrigation water applied able to minimise the water stress.

The corn water demand, the yield and the water use efficiency was estimated using the EPIC simulation model.

#### *2.4. A model for the evaluation of the economic impact of Climate Change*

The literature on the economic effects of CC on the agriculture sector (CEDEX, 2000, Christensen et al., 2002, Giupponi et al., 2003) is rich in long-term analysis at the aggregate level (e.g. Continental or National) and is instead deficient in short-term studies and on sub-regional areas level. In the case of the agricultural sector and the water management mathematical programming models can be used. This models can link the effects of CC to the variation of the water availability and the irrigation requirement and determine the effects of various scenarios on the use of production factors and income. Moreover, these models can consider the effect of uncertainty caused by climate variability on water availability (Dono and Mazzapicchio, 2010 (a) e (b)).

Among the various mathematical programming methods the Stochastic Programming Model (DSP) can represent a certain sequence of farmers' choices by considering that in some times (stages) these choices are made under uncertainty. (Cocks, 1968; Rae, 1971a and 1971b, MacCarl and Spreen, 1997). This because the conditions for the choice (states) are not known with certainty but only with a probability distribution. The DSP can thus represent the farmers' decision-making process as a succession of stages, each of which will make choices that affect conditions in which different possible states of nature. The decision maker does not know what state of nature should be, but each can give a possible outcome and a certain probability of success. Everything is well suited to represent the choices in agriculture that usually require several decisions are taken when their consequences or the results can not be known with certainty.

The DSP implemented in this study is a three-stages model with three states regarding the availability of water and two states related to the irrigation requirements. The first stage corresponds to the phase of the autumn sowing, the farmer decides the areas for each crop in autumn-winter and the areas to be left fallow for spring-summer crops. At this stage he does not know with certainty that water will be available in the irrigation season, but chose according to

expectations, assigning probability values to water availability scenarios (states of nature) that may occur. The second stage corresponds to the sowing of spring-summer crops and coincides with the start of the season in which the Consortium distributes irrigation water (April-October). This phase has now been completed on a state of nature on water availability in the dam and the farmer chooses to know the conditions. At that moment he can act only on the surface left uncultivated in the first stage. In the second stage may occur many states of nature as the availability of water varies because of the weather (precipitation and temperature) and for any public intervention that can promote uses such as drinking. However, in the second stage there is uncertainty on the irrigation requirements that depend of the temperatures that occur later (third stage). In particular, the model considers the uncertainty on the irrigation requirements of the corn.

Examining the time series of water availability in the territory under consideration, we chose to assume three states: *low*, *intermediate* and *abundant* availability (Dono and Mazzapicchio, 2010 (a) and (b)). That was when the abundance of water has no place limits on irrigation and other uses. The state of intermediate availability has been identified over the years in which the amount of water was limiting the scope for irrigation, but there was no need for public intervention rationing. The state of shortage occurred in years of emergency water, in which public authorities have seriously reduced the availability of water for agriculture to ensure the drinking water. Regarding the irrigation requirements of corn silage were assumed two states (*high*, *normal*) considering that the high temperatures, more frequent especially during the summer, can increase the evapotranspiration and thus the irrigation requirements.

The DSP model can be formalized as follows:

$$(1) \max_{x1, x3_{k,r}} Z = GI * x1 + P_k * P_r * GI_r * x3_{k,r}$$

s. to

$$(2) A * x1 + A * x2_k \leq b_k \quad \forall k$$

$$(3) A * x1 + A_r * x3_{k,r} \leq b_{k,r} \quad \forall k, r$$

$$(4) x3_{jsp,k,r} = x2_{jsp,k} \quad \forall jsp, k, r$$

where  $Z$  is the total gross income;  $x1$ ,  $x2$  and  $x3$  are the activities in hectares respectively of the first, second and third stage;  $P_k$  are the probabilities of the  $k$  availability water states;  $P_r$  are the probabilities of the  $r$  irrigation requirements states;  $GI$  is the gross income unitary of each activity,  $A$  is the matrix of technical coefficients and  $b$  are the quantities of available resources.

In the first stage the activities, for which the decisions are not directly affected by uncertainty about the availability of water in the dam, are considered: autumn-winter crops, fixed crops and



breeding activities. The second stage includes the spring-summer crops, decisions on which are directly influenced by uncertainties about the amount of water in the dam. Finally in the third stage occurring scenarios actually needs to irrigation with different levels according to temperature. Constraints (2) refer to the choices that are made in the first and second stage (e.g. land allocation), while constraints (3) also regards the choices for the third stage (e.g. water resource allocation). The level of surface crop sowing spring-summer (*jsp*) remains unchanged going from second to third stage by the constraints (4).

The model is solved with the program GAMS, General Algebraic Modeling System (Brooke et al., 1985), which generates a wide range of results, the main ones are discussed below.

The possible effect of CC was evaluated by comparing the results of two scenarios that represent the current state and future. The current situation, covering the period 1984-2003, is reproduced by applying the DSP model to the three availability conditions and two conditions of fodder maize irrigation requirements described above, with their probabilities of occurrence. In particular, it is considered as final result the average number of results generated by the model for each state, weighted by their probabilities. The projection of climate trends for the period 1996-2015 to estimate the probability values for future situation. These values are different for all states of both stages in which events are considered uncertain. Again, using these probability values included in a model of DSP have produced a series of results, weighted for their probabilities, have yielded an average result. The comparison between the average results of these two models show the variations of employment and income factors that could have the effect of CC. Furthermore, it was considered as an additional future scenario is different because the other considers only the effect of change in irrigation requirements and the variation in water availability. The comparison between the weighted average results for the relative likelihood of this scenario and the current can highlight the effects of CC due solely to changes in maximum temperatures.

### **3. The states of nature and the relative probability**

#### *3.1. The state of nature on the water availability*

For the first uncertain event, namely the availability of water in the dam Cuga, we consider three states of nature: low, intermediate and abundant. The reconstruction of states of nature on water availability in the current situation and the future is described in detail in Dono and Mazzapicchio, 2010 (a) and (b). Regarding the second uncertain event, namely the irrigation needs of crops, we have two states of nature, ie normal and high for irrigation of corn. To estimate the probability of occurrence of the two states is necessary to estimate a density function on the needs of irrigated corn, you know the values for the period 1961-2003. For this purpose, a function is determined for the period 1984-2003. Then, have defined levels which distinguish the density function. The lower

limit of normal state is equal to the minimum of the series, the higher is the value behind a demand equal to the irrigation technique normally used to cultivate corn. This value is the lower limit of the high state, whose upper limit is equal to the maximum value of the series. Defined the limits of the two states of nature in the density function if they are certain probabilities. The definition of the future scenario (1996-2015), has acted as already seen for the accumulation of water in the dam. In particular, there are certain intervals each of twenty-twenty years, beginning with the 1964-1983 and gradually moving the time interval of one year up to the period 1984-2003. They then estimated the density functions for each of these intervals and they are calculated on the probability of normal and high irrigation needs. These data were estimated linear trend values of probability for the two states of nature, which were then projected to the period 1996-2015 to obtain future scenario levels.

### 3.2. *The state of the nature on the irrigation requirements of the crops*

Regarding the second uncertain event, namely the irrigation needs of crops, we have two states of nature, ie normal and high. In this paper we will focus on corn silage, despite representing 0.7% of the cultivated area in the consortium and utilizes 6.4% of total water used, is essential for feeding livestock. To estimate the probability of occurrence of the two states of nature is necessary to estimate a density function on the needs of irrigated corn silage, which we know the values for the period 1961-2003. First, you can determine a function for the period 1984-2003. Next, we need to define the levels which distinguish the density function. The lower limit of normal state is equal to the minimum of the series, while the upper one is equal to the value that will underpin a demand equal to the irrigation technique normally used for growing fodder maize. This value is the lower limit of the high state, whose upper limit is equal to the maximum value of the series. To determine the probabilities of states of high and normal irrigation requirements is also necessary to determine the levels which distinguish the density function. As for the future scenario (period 1996-2015), has acted as already seen for the stadium on the accumulation of water in the dam.

## 4. Results

### 4.1. *Trend of the rainfall and of the maximum temperature*

The estimate trend shows a decrease in precipitation and a slight increase in maximum temperatures, as indicated by regression coefficients of their value over time (Table 1).

**Table 1. Trend of the rainfall and of the maximum temperature**

	Variable	Estimated coefficient	T – Statistic	Probability	R <sup>2</sup>
Rainfall	C	55.6454	13.6477	0.0	0.0149
	Time	-0.0381	-2.7904	0.0	
Maximum temperature	C	19.4988	37.2602	0.0	0.0149
	Time	0.0049	2.7875	0.0	

#### *4.2. Results of the agronomic model*

Due to the increased atmospheric CO<sub>2</sub> concentration, the simulated corn silage yields were significant higher (+6% ) in the second period (1984-2003) then in the first one (1961-1980). The increase of the air temperature causes the significant rise of the water consumption (+19.4%) with a consequent water use efficiency reduction (-10.3%). In August the evapotranspiration was increased of 18.3% from the first to the second period.

#### *4.3. Probability of each state of nature*

Regarding the levels of accumulation of water in the dam, the density function estimated for the period 1984-2003 can, once established values that surround the reservoir water levels were low, intermediate and abundant, to calculate its probability values. These values, for the present scenario, amount to 27.3% for the poor state of water accumulation at 40.7% for the reservoir level to intermediate and 32.0% for the rich. Projecting the trend of probability values obtained for each density function of the period 1961-2004, were obtained probability values for the scenario future. These values are equal to 38.8%, 13.7% and 47.5% respectively for the reservoir were low, intermediate and abundant

With regard to water requirements of corn fodder, first, you can determine a function for the period 1984-2003. The estimated function is represented by a Gambela with a value of statistical test Chi-square equal to 3.6000 and a P-value of 0.3080. The value of statistical test, the lowest compared to other distribution rent for the same set of data to indicate that this function represents the data better than others. To determine the probabilities of states of high and normal irrigation requirement is necessary to define the levels which distinguish the density function. Once defined these intervals were calculated relative probability values equal to 80.4% for the state of normal irrigation requirements and 19.6% for the state of high irrigation demand. The needs of this state is 9.7% higher than normal. Between the two countries also vary yields increasing by 6.5%.

Operating in a similar way to what was seen for the accumulation of water in the dam, were obtained probability values for the future scenario, representing 62.1% and 37.9% respectively for the reservoir were normal and high.

#### *4.4. Results of the DSP model*

The PSD model was first subjected to a validation process based on the comparison of cropping systems drawn from field observations in 2004 with those identified by the model for that year. Were used to compare the results of a model without the CAP reform in the current scenario using the Finger-Kreinin index, which assumes a value of 91.9 indicating that the model adequately replicates observed and production systems can provide useful information on the possible

adjustment of firms to changing economic conditions, structural and environmental. Here are the results of the model PSD obtained for the area served by the Consortium.<sup>7</sup>

#### 4.4.1. Economic results

The impact of CC leads to a slight decrease in total revenue and an increase in variable costs (Table 2). In particular there is a substantial increase in costs for the purchase of animal feed, for lifting water from private wells and paid work. Conversely, there is a reduction of costs for water supplied by the collective facilities of the Consortium for investment irrigation, and inputs. Gross margins of the total area reduce by 0.3%.

**Table 2. Economic results in the current and future scenarios – Absolute values (,000 €) and percentage variation**

	Current	Total CC	Only availability of water	Percentage Variation CC/Current	Percentage Variation Only water/Current
<b>Total revenue</b>	75,848	75,613	75,856	-0.3	0.0
<b>crop sales</b>	59,120	58,884	59,128	-0.4	0.0
<b>Variable costs</b>	19,876	20,134	19,913	1.3	0.2
<b>technical means</b>	15,179	14,961	15,188	-1.4	0.1
<b>animal feed</b>	102	587	118	473.0	15.2
<b>extra-farm labour</b>	2,646	2,736	2,665	3.4	0.7
<b>consortium water</b>	365	305	368	-16.4	0.7
<b>pumping water</b>	80	85	80	6.2	0.4
<b>investments for the irrigation</b>	1,503	1,460	1,494	-2.9	-0.6
<b>Gross income</b>	55,972	55,479	55,943	-0.9	-0.1

Limiting the analysis to the sole effects of changes in temperatures, and therefore in the water needs of irrigated corn, a slight decrease in gross margin emerges, -0.1%, which is due to a small increase in variable costs, caused mainly by an increase in food purchased.

Stronger results emerge when considering the gross margin of the types of farms in Table 3. The type most affected by CC is the dairy cow with a reduction in gross margin of 8.7%, which is mainly due to increasing costs for the purchase of food. Gross margin also decreases in the mixed type in sheep and olive, while increases in horticultural production. As will be seen later, this last takes advantage of the water no longer used for fodder, which makes it available for horticultural crops.

<sup>7</sup> The model is also not provided by the Consortium area, where companies engaged in dry farming. However, changes in the accumulation of water in the dam do not modify the choices of those types and, therefore, their results are not presented here.

**Table 3. Gross income per farm typology in the current and future scenarios - Absolute values (,000 €) and percentage variation**

	Current	Total CC	Only availability of water	Percentage Variation CC/Current	Percentage Variation Only water/Current
<b>Dairy cattle</b>	3,686	3,367	3,668	-8.7	-0.5
<b>Mixed</b>	20,559	20,349	20,594	-1.0	0.2
<b>Sheep</b>	4,574	4,543	4,569	-0.7	-0.1
<b>Olive groves</b>	5,234	5,219	5,234	-0.3	0.0
<b>Vineyards</b>	20,421	20,435	20,421	0.1	-0.0
<b>Horticultural</b>	1,499	1,566	1,458	4.5	-2.7

Again, the sole effect of changes in irrigation needs can be considered in this analysis. In this case, it can be seen that the small variations recorded for the total zone, are a summary of the reductions in gross margin affecting the horticultural, and appreciably, dairy farms, more limitedly.

#### 4.4.2. Use of land

The CC considered are reducing the irrigated area. In particular, there is a reduction in maize, horticultural crops (especially artichokes) in grasslands and pastures. Conversely, the area planted with watermelon and melon increases, Table 4. The area vacated by irrigated crops is used by other crops rainfed, especially barley and oats. Be noted that decreases the amount of forage on the farm and to meet the needs of cattle, the resort grows to purchases of feed, with the increase already seen in costs for animal feed.

**Table 4. Use of land in the current and future scenarios – Absolute values (ha) and percentage variations**

	Current	Total CC	Only availability of water	Percentage Variation CC/Current	Percentage Variation Only water/Current
<b>Cereal</b>	1,252	1,370	1,268	9.4	1.3
<b>corn</b>	992	645	949	-35.0	-4.4
<b>Horticultural</b>	1,610	1,490	1,595	-7.4	-0.9
<b>artichoke</b>	224	51	191	-77.0	-14.6
<b>watermelon and melon</b>	1,365	1,419	1,383	3.9	1.3
<b>Forage crops</b>	13,085	12,937	13,098	-1.1	0.1
<b>Grassland</b>	3,285	3,258	3,296	-0.8	0.3
<b>Tree crops</b>	2,677	2,677	2,677	0.0	0.0
<b>Total</b>	21,910	21,733	21,934	-0.8	0.1

By varying only irrigation needs, reduces the surface of vegetables, first of artichokes, and corn. Instead the cultivation increases of watermelon and cantaloupe, other cereals and grassland to replace, at least in part, the contribution of maize in the diets of cattle.

#### 4.4.3. Use of inputs

Change the future land use scenario induces a different use of inputs, Table 5. In particular, there is a strong reduction of water consumption provided by the Consortium of collective facilities and on the other hand, the increase that raised from wells. In total, however, water consumption decreases by 9.7%. The total use of labor remains unchanged since the family is replaced by the employee. Similarly the use of chemical inputs is the same level, although there are differences between the various factors. Increase the use of nitrogen and phosphorus and to reduce herbicides. Finally, as discussed above, increase the amount of feed purchased to compensate for the reduction of forage produced on the farm.

**Table 5. Use of input in the current and future scenarios – Absolute values (water in ,000 m3, labour in ,000 hours, chimica input in tons, animal feed in kg) and percentage variations**

	Current	Total CC	Only availability of water	Percentage Variation CC/Current	Percentage Variation Only water/Current
<b>Total water</b>	16,899	15,268	16,962	-9.7	0.4
<b>consortium</b>	14,185	12,418	14,240	-12.5	0.4
<b>wells</b>	2,715	2,850	2,722	5.0	0.3
<b>Totale labour</b>	2,192	2,180	2,193	-0.5	0.0
<b>farmer</b>	1,800	1,775	1,798	-1.4	-0.1
<b>extra-farmer</b>	392	405	395	3.4	0.7
<b>Nitrogen</b>	430	445	429	3.5	-0.1
<b>Phosphorus</b>	2,147	2,108	2,146	-1.8	-0.0
<b>Potassium</b>	2,284	2,280	2,291	-0.2	0.3
<b>Herbicide</b>	2.6	1.9	2.5	-26.7	-3.6
<b>Insecticide</b>	49.1	49.2	49.2	0.2	0.1
<b>Animal feed</b>	341	1,524	400	347.3	17.4

Limiting the CC to the change in temperatures, and hence in the irrigation needs of corn generates much smaller changes, but remains appreciable increase in the use of feed and reduction of herbicides. The other inputs remain almost unchanged.

## 5. Conclusions

This study provides an assessment of various economic impacts of CC on agriculture. In particular, a model PSD is used to simulate the response of farms to changes in rainfall, and hence the accumulation of water in a dam that irrigates, and temperatures, and therefore the irrigation requirements of field crops irrigated area in southern Italy. This model has produced different results when simulating the current scenario and future. Their comparison indicates some sort of degree of sensitivity of this system of agriculture change in the conditions of rainfall and temperatures. In particular, reduces the income of the types of farms more interested in producing irrigated crops such as vegetables, but also and especially dairy cattle. Furthermore, the increased

variability in reservoir water levels and rising temperatures, increase the exploitation of the aquifer. In addition, the increased use of nitrogen fertilizers for expansion in areas planted with grass and grain, increases the environmental impact of agriculture, increasing the risk of groundwater salinisation (Scholten and Szabolcs, 1993).

This study identifies some effects of interest related to the effects of CC on the use of natural resources such as the increased use of groundwater. Also, identifies the farm typologies that suffer most from the effects of CC. This helps in guiding agricultural policies that support the adaptation of the sector and poses some basic problems on the strategies to follow. In particular, as suggested by models of farms is a useful case study of production conversion compared to CC that could occur in the near future. In this case it is of interest the situation of the largest dairy farms, which may suffer most under CC predicted to 2015. In most of Sardinia, but it is the same for the rest of Italy, the farms that produce most of the bovine milk are similar to those represented by the model of this study. They are farms with high levels of production per head and many farm animals fed large amounts of water using surface or underground, to irrigate the corn. This productive model, dependent on abundant and stable water supplies, has already undergone a major impact from climate changes in the last twenty years. However, it seems especially threatened by the CC for the foreseeable future that defines a framework of instability in water availability and rising temperatures. Given the relevance of this model for milk production under Mediterranean climate conditions, the risk is run to losing the presence of Italian products in this sector. The results of the analysis indicate that agricultural policy is therefore urgent to develop adaptation measures to CC especially for this sector.

Finally, it should be noted that a contribution of this study was to evaluate several elements of CC, ie the change in water availability and level of temperature. A result, which is considered for the moment still preliminary, indicated that in the studied system, water availability is crucial because makes it less susceptible to temperature change. This is important because suggests that with good infrastructure and water resource endowment, the agricultural sector could adapt to the expected climate change scenario. The Agrosценari project, which funded this work and will fund its future development, will permit fruitful collaboration with climate scientists and patterns of cultivation and livestock, which permit defining articulated scenarios of such spatial models.

## **References**

Alexandrov V, Hoogenboom G (1999) Crop water use as a function of climate variability in Georgia. In: Hatcher KJ (ed) Proceedings of the 1999 Georgia Water Resources Conference. Institute of Ecology, The University of Georgia, Athens, GA, pp 425–428.

- Bazzani G.M., Scardigno A., 2009: *Un modello di simulazione territoriale per l'analisi economica dell'uso dell'acqua in agricoltura in presenza di cambiamento climatico*, paper presentato al XLVI Convegno SIDEA "Cambiamenti nel sistema alimentare: nuovi problemi, strategie, politiche". Piacenza, 16-19 settembre 2009.
- Bryant KJ, Benson VW, Kiniry JR, Williams JR, Lacewell RD (1992) Simulating corn yield response to irrigation timings: validation of the EPIC model. *J Prod Agric* 5:237–242.
- Dono G., Mazzapicchio G., 2009: *Effetti della Riforma Fischler e influenze dei Cambiamenti Climatici sull'attività di irrigazione in un'area del Mediterraneo*, paper presentato al XLVI Convegno SIDEA "Cambiamenti nel sistema alimentare: nuovi problemi, strategie, politiche". Piacenza, 16-19 settembre 2009.
- Dono G., Mazzapicchio G., 2010 (a): *L'impatto economico dei Cambiamenti Climatici sulla disponibilità di acqua irrigua in un'area del Mediterraneo*, *Economia delle Fonti di Energia e dell'Ambiente*, n.1/2010.
- Dono G., Mazzapicchio G., 2010 (b): *Uncertain water supply in an irrigated Mediterranean area: an analysis of the possible economic impact of Climate Change on the farm sector*, *Agricultural Systems*, Vol. 103, Issue 6.
- Dono, G., Marongiu, S., Severini, S., Sistu, G., Strazzer, E., 2008: *Studio sulla gestione sostenibile delle risorse idriche: analisi dei modelli di consumo per usi irrigui e civili*, ENEA, Collana Desertificazione - Progetto RIADE.
- Gassman P.W., Williams J.R., Benson V.W. Izaurre R.C., Hauck L.M., Jones C.A., Atwood J.D., Kiniry L.R., Flowers J.D., 2005. Historical Development and Applications of the EPIC and APEX Models. Working Paper 05-WP 397. 2004 ASAE/CSAE annual international meeting, Ottawa, Ontario, Canada. Meeting Paper No. 042097.
- Guerra LC, Hoogenboom G, Hook JE, Thomas DL, Harrison KA (2002) Predicting water demand for irrigation under varying soil and weather conditions. In: *Understanding and Addressing Conservation and Recycled Water Irrigation (2002 Conference Proceedings)*. The Irrigation Association, Falls Church, VA, [CD-ROM].
- Heinemann AB, Hoogenboom G, Faria RT de (2002) Determination of spatial water requirements at county and regional levels using crop models and GIS. An example for the State of Parana, Brazil. *Agric Water Manage* 52:177–196.
- Hoogenboom G, Jones JW, Boote KJ (1991) A decision support system for prediction of crop yield, evapotranspiration, and irrigation management. In: *Irrigation and Drainage Proceedings 1991*. IR Div/ASCE, Honolulu, HI, pp 198–204.
- IPCC (2007). *Historical Overview of Climate Change Science*.



- Kiniry JR, Williams JR, Vanderlip RL, Atwood JD, Reicosky DC, Mulliken J, Cox WJ, Mascagni HJ Jr, Hollinger SE, Wiebold WJ (1997) Evaluation of two maize models for nine U.S. locations. *Agron J* 89:421–426.
- Madrau S. et al., 1981. Rilievo integrale dell'area di Tuttubella (Sardegna nord-occidentale). *Atti dell'Istituto di Mineralogia e geologia*, vol. 2. Università di Sassari.
- Mc Carl B.A., Spreen T.H., 1997: *Applied mathematical Programming using algebraic systems*, disponibile on line su: <http://agecon2.tamu.edu/people/faculty/mccarl-bruce/mccspr/thebook.pdf>.
- Meinardus A, Griggs RH, Benson VW, Williams JR (1998) EPIC. The Texas A&M Blackland Research and Extension Center, Temple, TX. Available at: <http://www.brc.tamus.edu/epic>. Accessed on 31 Oct. 2001.
- Nijbroek R, Jones JW, Hoogenboom G (2003) Optimal irrigation strategy for a spatially variable soybean field: a modeling approach. *Agric Systems* 76:359–377.
- NOAA (National Oceanic and Atmospheric Administration), 2010. Mauna Loa CO2 annual mean data. Earth System Research Laboratory (ESRL) <http://www.esrl.noaa.gov/gmd/ccgg/trends/>.
- Solomon, S., Qin, D., Manning, M., Marquis, M., Averyt, K., Tignor, M. M. B., LeRoy, Miller H. Jr., Chen, Z. (2007), *Climate Change 2007 – The Physical Science Basis*. Cambridge University Press.
- Williams JR, Jones CA, Kiniry JR, Spanel DA (1989) The EPIC crop growth model. *Trans ASAE* 32:497–511.
- Williams, J.R. 1990. “The Erosion Productivity Impact Calculator (EPIC) Model: A Case History.” *Phil. Trans. R. Soc. Lond.* 329: 421-28.