Resilience of irrigated agricultural systems to climate change challenges in central-eastern region of Tunisia

Houcine Jeder [1*], Emna Ben Hamza[2], Hatem Belhouchette[2] and Aida Mzoughi[3]

1 *Researches Regional-Centre on Horticulture and Organic Agriculture (CRRHAB), B.P. 57, Chott-Mariem - 4042, Sousse – Tunisia/ Laboratory of economy and rural communities, Arid regions institute (IRA), Médenine-Tunisia.*

2 *International Center for Advanced Mediterranean Agronomic Studies (CIHEAM), Montpelier-France.*

3 *Faculty of Economics and Management of Tunis, University of Tunis El Manar. Tunisia*

∗ *Corresponding author: djederhoucine@yahoo.fr / djederhoucine@gmail.com*

Abstract

Tunisia is among the Mediterranean countries that are threatened by climate change. The agricultural sector is the economic sector that will be most affected by this phenomenon. Thinking of adequate adaptation policies to increase the resilience of certain agricultural production systems is a fundamental condition for ensuring the sustainability of agricultural activity, especially irrigated agriculture.

To assess the degree of resilience of irrigated agricultural production systems in the central-eastern region of Tunisia, case of Kalâa Kebira, a bio-economic model was applied to analyze the impact of two scenarios. The first represents only the variation of climate change while in the second one, we add an integrated policy based on the pricing of irrigation water and the subsidy of the purchase cost of seasonal potato seeds.

The results of the simulation confirmed the negative economic and environmental impacts of climate change on small scale intensive farms and also large farms in general. The intervention of the public government through an integrated policy is likely to improve the degree of resilience of farms through a compromise between the economic objective (the agricultural income) and the environmental objective (soil salinity) for semi-intensive farms in the study area.

Keywords: Climate change, resilience, modeling, agricultural production system, central-eastern of Tunisia.

Introduction

In Tunisia, the current use of water in agriculture depends mainly on rainfall which leads to an irregular demand. This is expected to increase in the future with the intensification of the use of water resources and extension of irrigated public perimeters. The irrigated areas increased from 120,000 ha in 1972 to 315,000 ha in 2015. It is expected that this will cover 450, 000 ha in 2025. This extension of irrigated public perimeters has been accompanied by an improvement in intensification rates of irrigated land and water use. This rate increased from 80% in 1986 to 104% in 1996. The highest intensification rates for irrigated agriculture in terms of irrigable land use have been recorded in the oases of Cape Bon and the Sahel on the center but they remain relatively low in the north-west of the country (Mamou, 2000).

The mobilization of water use in agricultural increased from 59% of the total availability of irrigation water in 1990 to 93% in 2005 thanks to large and medium hydraulic installations such as dams, hill dams, hill lakes, deep and surface drilling (Zaara, 2008). The creation of these irrigated public constitutes the principal means for the agricultural development process in certain regions through the creation of jobs and the fixing of the rural population in order to limit the rural exodus. Agriculture in irrigated public perimeters is an alternative source of income for many farmers in these rural areas, especially farmers with small areas of agricultural land (Sellemi et al., 2007).

In this context, specialization in certain agricultural production activities has become a regional agricultural specification for irrigated agriculture practiced by some Tunisian farmers. Recently, the development of a new agricultural production system based on vegetable crops associated with arboriculture is considered the most suitable agricultural system for some farmers. This system of agricultural production was appreciated by farmers in these regions, specifically the region of "Kalâa Kebira" on the governorate of Sousse, in central-eastern Tunisia. This new agricultural production system relies on vegetable crops, mainly potatoes (seasonal potato, late season potato and early season potato) and rarely on other crops such as vegetables like pepper. This system of intercropping with olive trees has almost become a strategic agricultural activity in this region.

In recent years, despite the success of the development of a new agricultural production system, farmers in this region are facing several of problems. Some problems are related to climate change and its impacts on the availability of irrigation water resources in the last agricultural companions. Others are related to the economic situation of the country, which is characterized by high inflation and depreciation of the national currency "Tunisian Dinar" thus affecting the instability of prices of agricultural inputs imported especially seeds for seasonal potato crops.

Given the constraints and challenges raised, an assessment of the socio-economic and environmental sustainability of these new agricultural production systems has become a necessity for farmers as well as for local actors. So the interest of this study is to provide clarification on the degree of resilience of these new agricultural production systems developed. These clarifications can serve as points of reflection for local decision-makers for the implementation of climate change adaptation strategies in this region.
The rest of this article is structured as follows: The literature review is presented by section 2. The methodology used which includes the presentation of the case study, the collection of survey data and the modeling part is developed in section 3. The different results obtained are discussed in section 4 and the conclusion in the last section.

Literature review

The question dealing with the problem of adaptation of agriculture to climate change is multiplied in the field of scientific research because of the importance of this issue for economic activities and mainly agriculture. The importance of this issue stems from the crucial role of agriculture in the contribution of the economy and the food security of a country. So the development of decision support tools in agriculture by linking with the climate change issue can only be beneficial outputs for local, national or international decision-makers to establish strategies for adaptation to climate change.

In this framework of analysis, several methodological approaches have been developed to address the problem of climate change. In agriculture, almost two types of economic approaches that are often used to assess the impact or adaptation to climate change: the econometric approach and the bioeconomic approach.

The econometric approach is categorized depending on how these adaptations are estimated. Amongst them, we found methods which estimate adaptations through cross-sectional statistics and econometric techniques (Mendelsohn et al., 1994) also known as Ricardian approach; and those which used geographic information systems combined with an economic model, also known as duality-based models (Darwin et al., 1995). however, two major drawbacks are commonly mentioned in literature: 1) the assumption of no feedback of changes in land prices on agricultural prices, ignoring future impact of price changes over domestic and foreign supply and demand; and 2) the fact that this approach can only capture the effects observed in the data, which puts into question its plausibility for long-term projections (Nelson et al., 2014).

The bioeconomic approach, on the contrary, includes changes in land values within the economic models so that the responses of all economic agents are explicitly, including also the direct effects of specific farm-level adaptations. This interdisciplinary approach interlinks models from several disciplines. The most common approach in this approach is to use biophysical models to predict crop yield and the effects of externalities generated by agricultural production under climate change scenarios to be tested, which are then used as inputs into the economic model to predict future socio-economic and environmental effects (Figure 1). These methods have been applied at different geographical scales and with different treatment of the economic dimension using the aggregation method (Fernández and blanco, 2015).

Although important advances have been observed in the integration of biophysical and economic modeling for the assessment of climate change, currently, there are also some limitations regarding aggregation of scales, interaction and effects between agricultural activity and livestock in the climate change context. In the same critical spirit, a harmonization of adaptation options with the reality and specification of the region regarding the problem identified could be a great help to understanding the uncertainty of management practices.

In this research, a bioeconomic modeling based on a coupling between a biophysical model and an economic model of the exploitation was used as an ex-ante evaluation tool for the degree of resilience of agricultural production systems in central-eastern Tunisia.

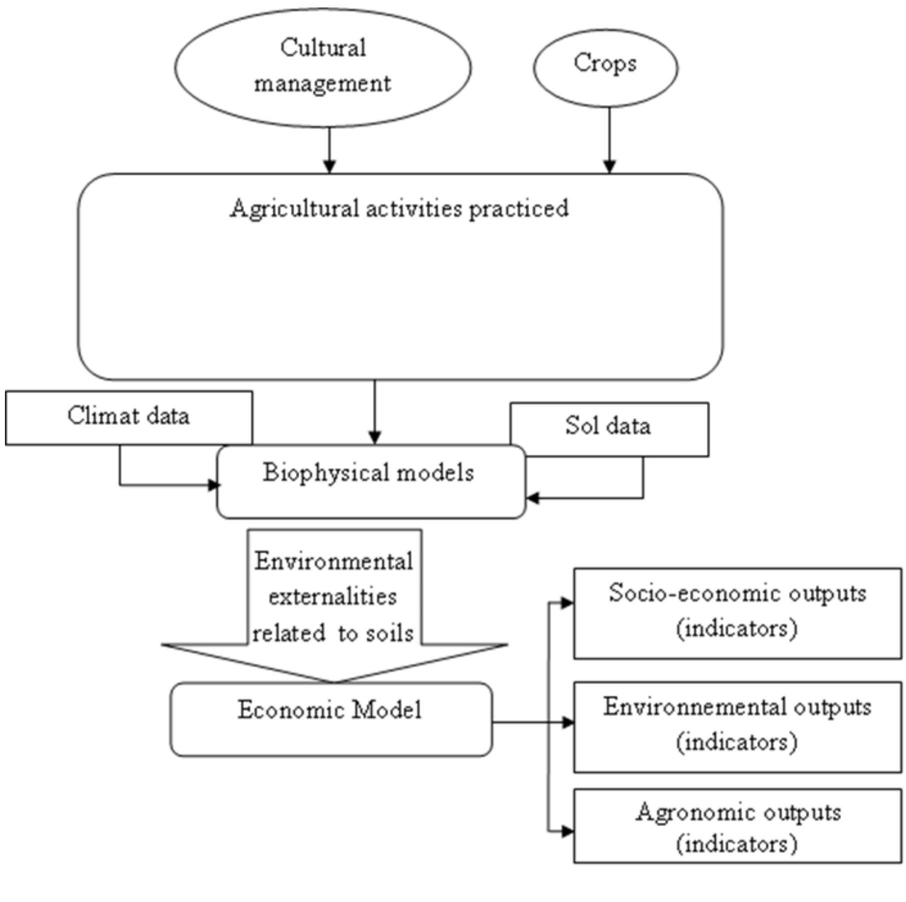

Fig. 1. *- Bioeconomic model*

Methodology and area of study

Study area

The case study is the irrigated public perimeter of Kalâa Kebira, which is located northwest of the city of Sousse and is irrigated from the “Nebhana dam” and large hydraulic boreholes. This perimeter was created in 2003; it is occupied by arboriculture based on olive and vegetable crops focused mainly on the potato on large expanses interposed with the feet of olives.

This irrigated public perimeter covers an area of 540 ha managed by two “Grouping of Agricultural Development”, called locally “GDA”, "Chiab" and "Bâloum". It includes 199 farms owned by 186 farmers (CRDA, 2015).

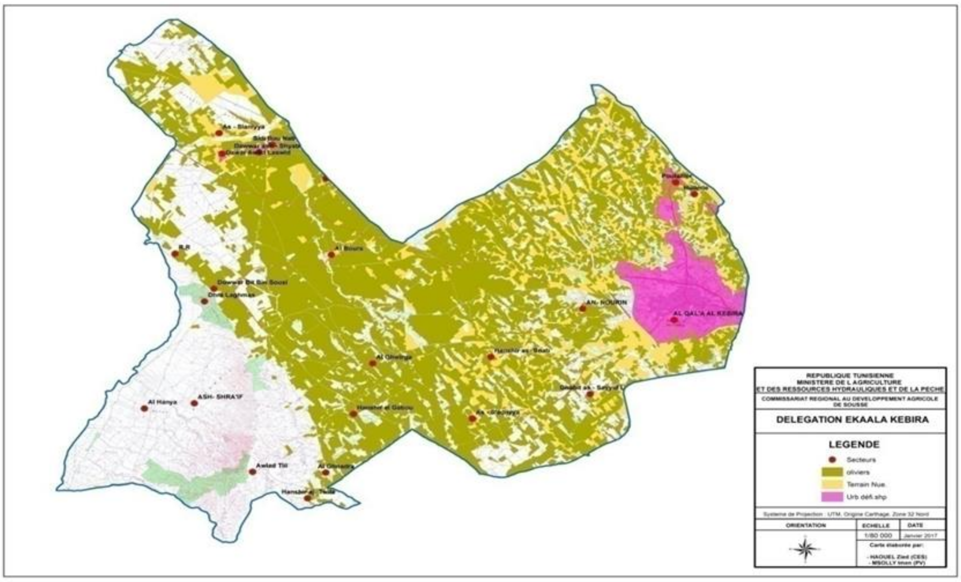

Fig. 2. *- Case study: Kalâa Kebira region, Sousse governorate, east-central Tunisia*

Data acquisition

A survey was conducted during the 2016-2017 farming season. This survey involved 65 farms in the areas of “Bâloum” and “Chiab”. The sample size was determined by the proportion method. It represents 35% of the total population (N=186farmers). This survey allowed us, first, to know the socio-economic characteristics of the farms surveyed. Secondly, to have the essential data to feed the models mobilized in the framework of this study as: the economic, structural and agronomic data of the farms.

The techno-economic coefficients associated with productive activities come from the techno-economic fact sheets filled out by farmers and experts in the region. For environmental coefficients as well as soil externalities caused by agricultural activities are generated by the biophysical model (CropSyst) (Stöckle et *al.*, 2003).

Bio-economic modeling

The methodological approach used is based on bio-economic modeling. It is a coupling between a biophysical model and an economic farm model (Flichman *et al.*, 2003). In this research, a CropSyst biophysical model was coupled to an FSSIM economic model (Farming System Simulator).

The CropSyst model was used to estimate the coefficients of soil-related externalities taking into account climatic conditions, soil types such as soil salinity in our study. Knowing that the salinity of irrigation water used in agriculture exceeds 2g /liter, this salinity value will worsen in future years with the context of climate change and water scarcity as well as the lack of leaching by rainwater (Belhouchette, 2005).

FSSIM economic model has been developed as part of the integrated modelling framework of the System for Environmental and Agricultural Modelling; Linking European Science and Society (SEAMLESS) (Van Ittersum *et al.*,2008),. It is a generic and modular model designed to assess the impact of agricultural and environmental policies on the sustainability of production systems in Europe but also outside Europe where data are available (Louhichi *et al.* 2009).

The mathematical formulation of FSSIM

FSSIM is an optimization model which maximizes a farm's total gross margin subject to a set of resource and policy constraints. Total gross margin is defined as total revenues including sales from agricultural products minus total variable costs from crop production. Total variable costs include costs of fertilizers, costs of irrigation water and crop protection, costs of seeds and plant material and costs of hired labour. The general mathematical formulation can be presented as follow:

Maximize: $U = Z - \varphi\sigma$ (1)

Subject to: $Ax \leq b, x \geq 0$

Where U is the objective function to maximize, Z is the expected income, x is the $(n \times 1)$ vector of the simulated levels of the agricultural activities, φ is the risk aversion coefficient which is different between farm types, σ is the standard deviation of income due to price and yield variation, A is the $(m \times n)$ matrix of technical coefficients, and b is the $(m \times 1)$ vector of available resource levels and upper bounds to the policy constraints.

The agricultural activities *(i)* are defined in FSSIM model as a combination of crop rotation *(r),* soil type *(s),* period *(p),* production technique *(t)* and production orientation *(sys)* (i.e. $i=r,s,t,sys$). Thus, the agricultural activity identified is defined through a set of elements describing the management and the technical itinerary practiced for each crop.

The principal technical, socio-economic and environmental constraints that are implemented in the FSSIM model are: arable land per soil type (or agri-environmental zone), irrigable land, labour, water for all of these constraints defined: the sum of the requirements for each resource cannot exceed resource availability. The environmental constraint calculates the salinity at the farm level by summing the salinity generated by each agricultural activity practiced (Abess, 2005).

Policy scenario

To evaluate the degree of adaptation of these new agricultural production systems to the challenge of climate change, two scenarios for the 2030 horizon have been developed to answer this question. These scenarios reflect the economic reality of agriculture in the region as well as the possible and acceptable instruments that can be deployed by local decision-makers in the future. These scenarios are as follows:

Climate change scenario (SC1)

This scenario reflects the reality of the phenomenon of climate change and its impact on agriculture and water resources according to the HadCM3 model results for the Mediterranean region, in particular for Tunisia, which foresees a decrease in water resources of around 5% to 25% (IPCC, 2007). By analogy, we will assume in this scenario not only a decrease of about 5% in the availability of water resources at farm level but also a 5% decrease in irrigable land area as a consequence on the choice allocation of land by farmers in the face of adverse weather conditions

Integrated Policy Scenario (SC2)

It is an integrated economic scenario but it is also an incentive scenario (SC1), which integrates both pricing policy through irrigation water pricing and subsidy policy to help farmers adapt to predicted climate change scenario (+ SC1). This time, we are going to assume a subsidy of 10% of the cost of purchasing seasonal potato seeds (imported seeds) and an increase in the price of irrigation water of 15% in a future context of change climate. These two scenarios are summarized in the following table (Table 1).

Tab. 1. *- Description of the scenarios used*

Scenarios		Description of scenarios
Integrated economic scenario (SC2)	Climate change scenario(SC1)	Decrease 5% of water availability resource and 5 % irrigable land area
	Irrigation water pricing policy	Increased in the price of water by 15%
	Subsidy policy	Subsidy of 10% of the cost of buying seasonal potato seeds

Results and discussions

Farm typology

In order to give a representative image of the current farming systems in the selected region and to capture heterogeneity among farmers, a typology of farms is an adequate tool to present the different agricultural production systems practiced (Hazell et Norton, 1986).

A typology was made from the data collected in 65 farms surveyed. In these farms are grown mainly potatoes and other vegetable crops (such as tomato and pepper) intercropped with the olive tree. Principal component analysis and hierarchical classification was performed. The analysis was based on three criteria; source of irrigation water ("Nebhana" dram or large hydraulic boreholes); farm size (small farm <5 ha; 5 ha≤ average farm<10; larges farm ≥10) and agricultural orientation (System 1: Olive / Potato; System 2: Olive / Potato / other vegetable crops and System 3: Olive / Potato / Others crops). Principal component analysis and hierarchical classification have identified the presence of four typical farms of agricultural production systems in the studied area (Figure 2).

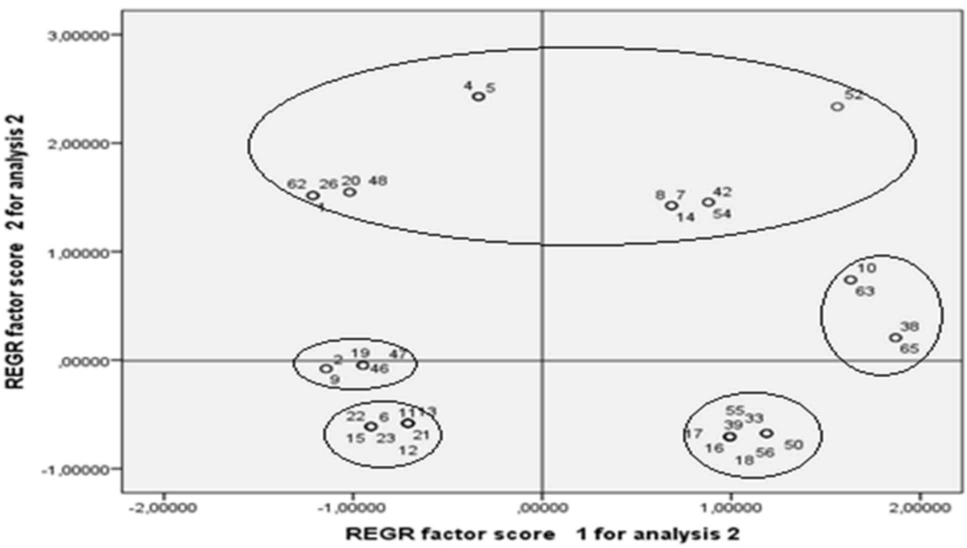

Fig. 3. *- Farm typology (Realized by SPSS software)*

All the farms identified are marked by the same production system orientation. This typology confirms that this new system of agricultural production based on vegetable crops intercropping with the olive tree is a specific and strategic production system for the farmers of this region and the heterogeneity is only in the size of the farm and the source of irrigation water. The crops grown for these 4 typical farms are the potato for the 3 seasons, the pepper intercropped with the olive tree with the presence of fallow.

The farm type **EXP1** is a representative of an intensive agricultural production system on small agricultural area 2.65 ha of which 2.5 ha is irrigated land. It is located on both types of soil with respectively 0.56 on soils of type S1 and 2.11 ha on soils of type S2. It represents 65% of farmers surveyed.

The farm type **EXP2** is a representation of an intensive agricultural production system with a total agricultural area of 5.75 ha of which 5.5 ha is irrigated land. It is average farm type located mainly in the region of Bâloum; of which 86% of the area (ie.5 ha) are found on soils type S1 against 14% (0.75 ha) on soils of types S2. This farm type represents 6% of farmers surveyed.

The farm type **EXP3** is a representation of a semi-intensive agricultural production system on an average agricultural area of about 6.5 ha of which 5.16 ha is irrigated land. This farm type is located on the two agri-environmental zones with respectively 54 % (3.5ha) on soils type S1 and 46 % (3 ha) on soils type S2. This farm type represents 22% of farmers surveyed.

The farm type **EXP4** is a large representative farm of semi-intensive agricultural production system on a large average area of 14.20 ha of which 13.8 ha is irrigable land. 82% (11.6 ha) of the area is located in zone S1 against 18% (2.6 ha) located in zone 2. This farm type represents 8% of farmers surveyed.

All the characteristics of farms types are shown in the following table (Table 2.)

Tab. 2. *- Main characteristics of the four farming systems*

Farm types	**EXP1**	**EXP2**	**EXP3**	**EXP4**
Available water (m3)	8779,78	18968,18	19132,66	50730,62
Irrigable area (ha)	2,5	5,5	5,16	13,8
Family labour (hours/ha/year)	1714,29	1800	1800	1200
Soils types (ha)				
S1 Xerosoils	0,56	5.00	3.5	11,6
S2 Fluvisols	2,11	0,75	3.0	2,6
Observed crop pattern (ha)				
Seasonal potato	1,02	2,05	1,53	5,1
Late-season potato	0,85	0,25	0,69	3,75
Early potato	0,06	2,05	1,75	2,55
Olive	0,06	0,15	0,13	0,22
Vegetables (pepper)	0,26	0,25	1,05	1,9
Fallow	0,42	1	1,35	0,68
Total area (ha)	***2,67***	***5,75***	***6,5***	***14,2***

Source : Survey data 2017

Calibration models

Before scenario simulation, a bio-economic model calibration phase is necessary. The calibration of the models used in the bio-economic modeling was done successively for the biophysical and economic models but in a separable way (Reidsma et al., 2007).

CropSyst model calibration is based on the comparison of the simulated and observed agricultural yield for each agricultural activity practiced. 80% of the activities practiced having a difference between simulated and observed performance does not exceed 15%. We can say that the model is well calibrated to the climatic and pedagogical conditions of the region, so it is ready to simulate yields and externalities (salinity) for each activity.

It should be noted that the biophysical model is unable to simulate arboriculture, especially the olive tree in our case. It has been assumed that externalities (salinity) caused by the olive tree are null (it is zero).

Economic model calibration is based on the coupling of the risk method and the standard approach of the Positive Mathematical Programming (PMP) (Howitt, 1995). It consists in first choosing the risk aversion coefficient that allows to give the best deviation between the observed and simulated values and then to apply the standard approach of the PMP to calibrate the model in an exact way (Jeder et al., 2014).

Model calibration was tested by comparing the results of the crop allocation simulated by the model (simulated value) and the crop allocation observed in the base year situation in 2016 (observed value). The difference between both values is assessed statistically by using the Percent Absolute Deviation (PAD). The results of the calibration without Positive Mathematical Programming (PMP) for the four farm type are presented in Table 3. As shown in this table, the PAD obtained in the first step for the four farm types is not much higher than the fixed 15% threshold, which implies that firstly, the model quality in terms of specification of activities, constraints and the objective function is good and secondly, the terms of the PMP will not influence so much the results of the model in the simulation phase. Then the model has been calibrated for the four farm types (i.e. PAD equal to zero). The model can be used for simulation.

Tab. 3. *- Results of model calibration*

Farm types	**Code in GAMS**	**EXP1**		**EXP2**		**EXP3**		**EXP4**	
Area (ha)		Obs.	Sim.	Obs.	Sim.	Obs.	Sim.	Obs.	Sim.
Olive	OLIV	0,06	0,06	0,15	0,15	0,13	0,13	0,22	0,22
Vegetables (pepper)	FVEO	0,26	0,26	0,25	0,25	1,05	1,05	1,90	1,90
Potato Season	SPOTA	1,02	1,02	2,05	2,05	1,53	1,53	5,10	5,10
Early season potato	PPOTA	0,06	0,06	2,05	2,05	1,75	1,75	2,55	2,55
Late-season potato	ASPOTA	0,85	0,85	0,25	0,25	0,69	0,69	3,75	3,75
Fallow	FALL	0,42	0,42	1,00	1,00	1,35	1,35	0,68	0,68
Total area (ha)	TOTLAND	2,67	2,67	5,75	5,75	6,5	6,5	14,2	14,2
PAD (%) without PMP	***MIN PAD***		***78,22***		***47,19***		***63,92***		***73,03***
PAD (%) with PMP	***PAD***		***0,00***		***0,01***		***0,02***		***0,01***

Source : Model results

From Table 3, two interesting interpretations are deduced, the first concerning the coefficient of risk aversion, this coefficient is very high (1.65) for large farms against a coefficient of 1.25 for small farms. It can be deduced that in irrigated agriculture, Small farms are a risky month in view of the irregularity of agricultural yields and the instability of prices of agricultural products.

The second interpretation concerning the value of PAD, the PAD obtained at the first stage for the four farms is a little higher than the threshold of 15%, which implies on the one hand that the number of activities is very small compared to the many of the constraints and their specifications are rigid in terms of crop rotation. Despite these limitations in the design of activities, PMP's approach is able to accurately calibrate and replicate the base year crop area with a PAD value of almost zero. Once the bio-economic model is calibrated, it is ready to do simulations of proposed scenarios.

Analysis of scenarios

To analyze the impacts and the degree of adaptation of the different agricultural production systems to climate change, a set of socio-economic, environmental and agronomic indicators (modeled outputs) have been interpreted. These indicators are as follow:

- Economic indicators: farm income (DT / ha), costs (DT / ha), labor (h / ha)
- Environmental indicators: water use (m3), soil salinity (dS /m)
- Agronomic indicators: land use by crop (ha)

Climate change scenario impacts (SC1)

From Figure 4, model results shows that climate change has negative impacts on farm income for the different farming systems represented by typical farms identified. The economic impact is important on medium and large farms. Indeed, we note the decline in agricultural income that exceeds 3.5% for farms EXP1, EXP3, EXP4 while for farm EXP2, the decline in agricultural income is a little light. These results show that intensification cannot sustain agricultural income in a context of climate change because of the decline in agricultural yields caused by the decrease in agricultural area and the availability of water resources. Farms that are highly used inputs production such as irrigable land and water will be most affected, especially for small intensive farms or large semi-intensive farms.

In the same Figure 4, the climate change affects other than the farm income, the employment of the agricultural labor force since the irrigable land is decreased and the availability of water resource is very limited. The need for agricultural labor will therefore be very limited. The lower cost of production explains why climate change will reduce the development of agricultural activities requiring factors of production such as water and agricultural labor.

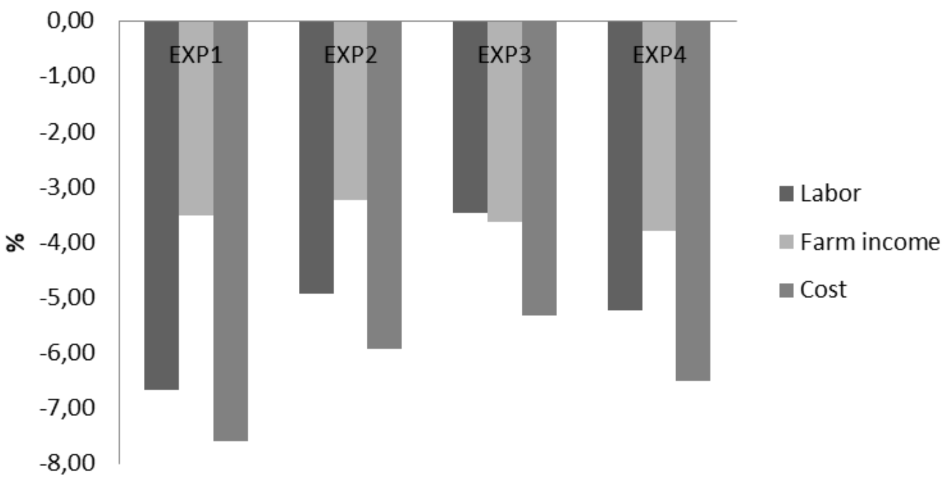

Fig. 4. *- Economic impacts of scenario SC1 (% base year_2016)*

In terms of environmental impact, the climate change scenario shows a reduction in the use of water for all farms (Figure 5). The farm EXP4 representing semi-intensive agricultural production system with a large area, the reduction of water use is significant, exceeding 5%. While for the other farms the farmers use all available water and the constraint of water availability is saturated for farms EXP1, EXP2 and EXP3. These results confirm that irrigation water will be a limiting factor for irrigated agriculture at the scale of large farms.

For externalities, the model shows that climate change contributes to the increase of salinity at the small farm level EXP1 compared to the baseline year scenario. These results show that the intensive system is a source of environmental problems when poor water availability and intensification multiply on reduced irrigable lands and leaching by additional irrigation is impossible. On the other hand, there is a decrease in salinity for medium and large farms characterized by a semi-intensive production system (Figure 5).

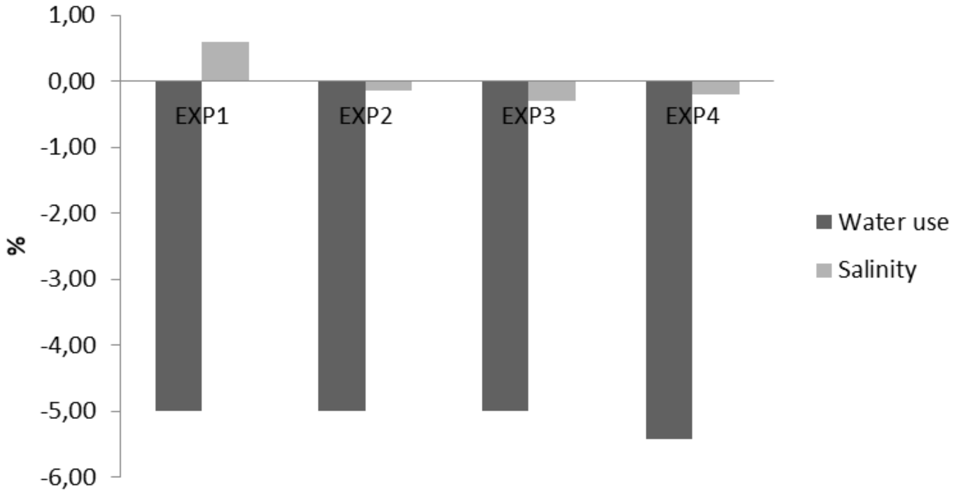

Fig. 5. - Environmental impacts of scenario SC1 *(% base year_2016)*

Impacts on land use by crops, the Figure 6 show that decreasing availability of water resources and irrigable land has led to a change in land allocation. On one hand, a complete disappearance of fallows for the benefit of the other most profitable crops was noticed, on the other hand, a reduction in the area allocated to pepper crops for farms EXP1 and EXP4. Whereas for medium-sized farms, the areas allocated to these crops are disappearing at the farm level EXP2 and a slight increase is observed for the farm EXP3. The largest decrease in agricultural area was remarkable for the area allocated to pepper crop at the farm level of EXP1, the areas allocated to the early potato crop at the farm level EXP2 and EXP3 and the areas allocated to the late-season potato crop at the farm level EXP4. This reallocation aims to find the most profitable activities while respecting hypothetical conditions imposed by the climate change scenario.

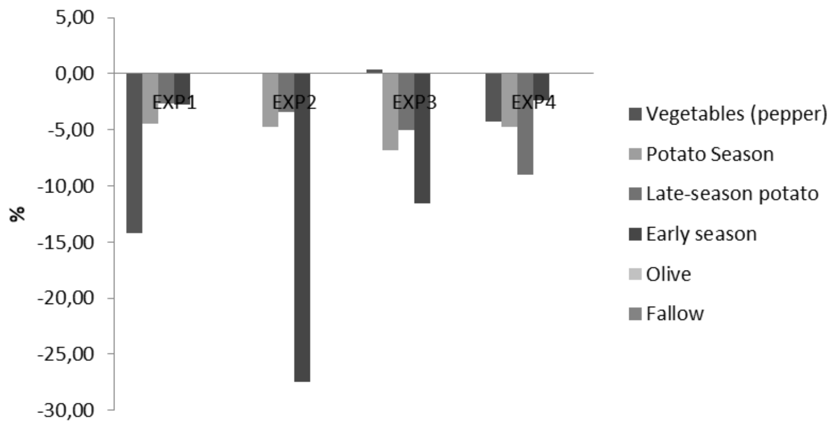

Fig. 6. - Impact of scenario SC1 on areas of crops (% base year_2016)

These results confirm the results shown by several studies around the world that climate change will have adverse economic and environmental impacts for farms (Roco et al, 2017, Gunnarsson, 2017). Similarly, the results of this research show that agricultural intensification with factors of agricultural production limited by climate change such as water and irrigable land will increase the degradation of the land by salinity and deteriorate the income of small farms. It can be deduced that household farms will be the first to be threatened by climate change.

Integrated policy scenario impacts (SC2)

The results of integrated policy scenario (SC2) based on the subsidy of the purchase of seasonal seed potatoes (10% of purchase cost) and the pricing of irrigation water (the increase of 15% water prices) in the context of climate change (scanrio1) show diversified results for the different farms, but they are economically and environmentally beneficial for some of them.

At the economic impact level, Figure 7 show that the results of the Integrated Policy Scenario have a significant increase in farm income for small farms EXP1 and a slight increase in the level of large-scale farm EXP4. These results show that in climatic conditions characterized by a decrease in water availability and irrigable areas, small farmers manage to support the increase in the price of irrigation water and that the subsidy reduces the cost of agricultural production. For EXP4 farms, the increase in agricultural income remains low despite the lower cost of agricultural production. This scenario shows that medium and large farms are not able to maintain their farm incomes compared to the 2016 base year, despite the lower cost of production and the employment of agricultural labor.

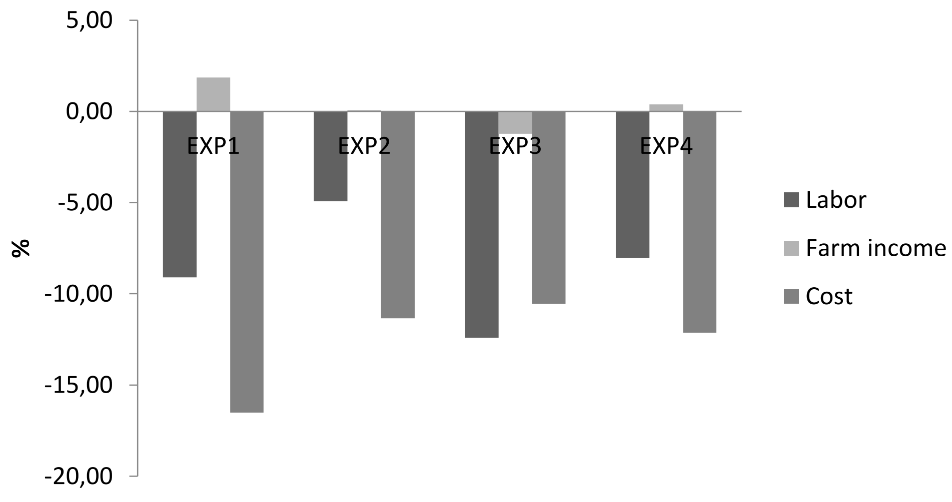

Fig. 7. - Economic impacts of scenario SC2 (% base year_2016)

For environmental impact (Figure 8), an increase in soil salinity for small farms EXP1 and large farms against a significant decrease in the level of exploitation EXP3 and stability for exploitation EXP2. For the use of irrigation water, the results are the same as the scenario SC1. The irrigation water constraint is saturated in the EXP1, EXP2 and EXP3 farms and a slight decrease in the EXP4 farm scale. These results show that in a context of climate change characterized by water scarcity, the pricing policy does not have significant effects on the consumption of irrigation water. The demand for irrigation water remains stable when irrigated agricultural activity is the main economic activity for rural households. The demand for water becomes inelastic, the behavior farmers do not react to the increase in price of irrigation water and they take maximum advantage of the availability of water offered in order to sustain their income and ensure the sustainability of their agricultural activities.

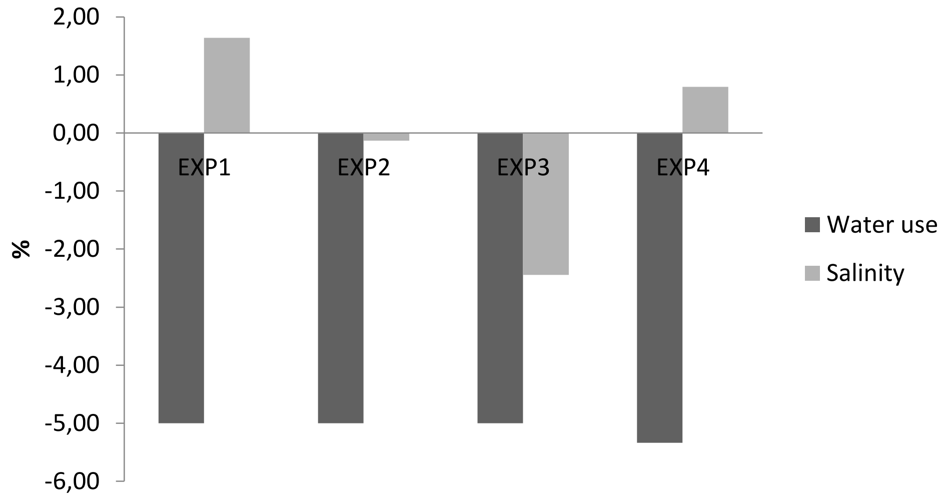

Fig. 8. - Environmental impacts of scenario SC2 (% base year_2016)

Impact at the scale of land use by crops, the figure 9 shows a very significant increase in the area of the seasonal potato on the farm scale EXP3 against the stability of area at the farm scale of the farm and a significant decrease at the farm level EXP1 AND EXP2. A significant decrease in the area allocated to pepper crop that disappear at the farm level EXP2.

These results show that this scenario (SC2) was beneficial for medium-sized farms characterized by a semi-intensive agricultural production system EXP2 despite farm income remaining almost stable; the environmental result was encouraging in terms of reducing soil salinity. Achieving a trade-off between the economic objective and the environmental objective is a fundamental point for ensuring the sustainability of farms in a context of heightened climate change in the study area.

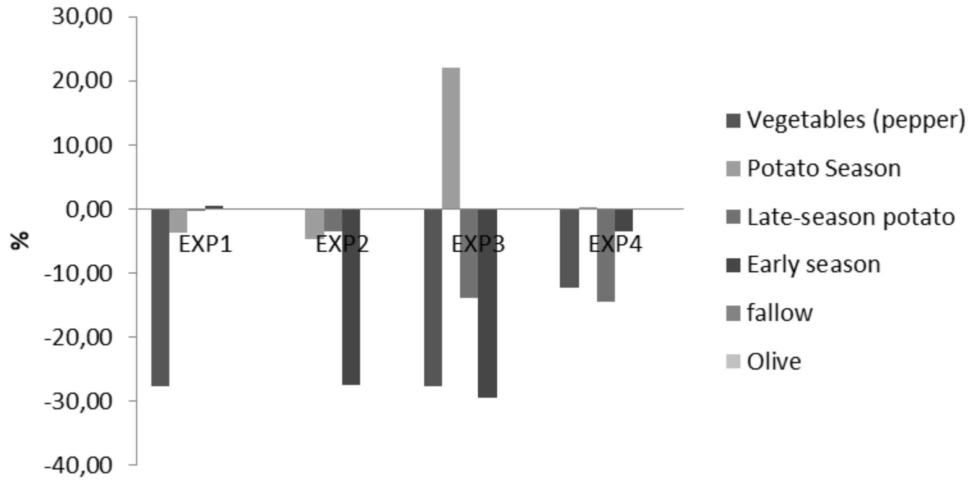

Fig. 9. - Impact of scenario SC2 on areas of crops (% base year_2016)

The application of bioeconomic modeling has shown the degree of resilience of different production systems to climate change. The results of this application confirm the results obtained in other studies using the same FSSIM model. For example, the assessment of the impact of climate change on arable farming systems in the Midi-Pyrenees regions greatly depends on the characteristics of the different production systems (cereal / cereal and fallow / mixed). The degree of resilience to climate change is different from one production system to another, but the different scenarios tested confirm a reduction in farm income, a decrease in the demand for labor, land and a diversification of production (Mahmoud, 2011). Similarly, the application of this model in the Dutch province Flevoland showed that impacts of climate change were relatively less positive for very large farms than for smaller farms. This is related to the relatively large share of potato area on very large farms. When farm level adaptation was included, impacts were however similar on all farm types, as larger farms have more capacity to increase the area of other arable output (mainly flower bulbs). The difference in impact among farm size classes was larger for price and policy changes (Reidseima et al, 2007).

In Tunisia, the same FSSIM model was used to simulate irrigation water pricing in arid zones, also confirmed that the water price increase is an important economic regulating instrument for saving water and also an incentive for adaptability of irrigated agricultural production systems to the constraint of water scarcity due to climate change (Jeder et al, 2014).

Conclusion

The objective of this work is to test the degree of resilience of farms to climate change in the central-eastern region of Tunisia, case of Kalâa Kebira, governorate of Sousse. To answer this question scenarios have been developed: a climate change scenario and an integrated policy scenario. These scenarios were tested for the 2030 horizon, a bio-economic modeling approach based on the coupling of a biophysical model and an economic model was mobilized.

The results of these scenario simulations provided insight into the socio-economic profitability and environmental efficiency of agricultural production systems in the Kalâa Kebira region from the typical farms.

It should be noted that farms react differently according to the size of their areas (agricultural area available). In the context of climate change, a significant drop in income is recorded at the scale of intensive farms of small sizes and large farms, but for externalities, an increase in salinity is noted that at the scale of intensive farms. These results are explained by the change in land use by crops and the total disappearance of fallow land.

However, in terms of economic impact, the integrated policy scenario shows that beneficial results for small farms and acceptable for large farms. On the other hand, in environmental terms, these farms recorded an increase in soil salinity.

These results show that integrated policy has advantages and disadvantages for irrigated agriculture in the study area, but the search for a compromise between economic and environmental objectives is possible. For example, medium and semi-intensive farms EXP2 show an acceptable degree of resilience. Indeed, in a context of climate change; Farmers, who are able to maintain their income while reducing soil salinity on their farms, are farmers who are trying to adapt to maintain the sustainability of their farming activities. These results also show that public policies can help improve farmer behavior so that they are aware to adapt to the climate change context.

In methodological terms, bio-economic modeling has shown an ability to answer our research question on the degree of resilience of farms irrigated to climate change by simulating the impact of policy instruments across a set of economic, social and environmental indicators. However, this work can be improved in the future by integrating livestock activity that is important in the region and other policy instruments through a regional household model.

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