Bio-economic modelling to assess the impact of water pricing policies at the farm level in the Oum Zessar watershed, southern Tunisia

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Abstract

For integrated assessment at farm level, the Farm System SIMulator model (FSSIM) was used. FSSIM is a bio-economic model developed for the European context, and was adapted and tested for Tunisian conditions to assess, ex-ante, impacts of water pricing policies at the farm level to the year 2015.

The results show that all farm types are strongly dependent on the water pricing policy. Farmers that have private irrigation systems and pay for pumping mainly, are more sensitive to the progressive increase of irrigation water costs compared to farms that obtain water from public irrigation systems, who pay for the amount of water received. A sensitivity analysis showed that increasing the water price with more than 17% is not advisable to local decision makers, because the net income continued to decline, while the water consumption remained stable with further increases. Hence, there is no further gain in terms of water saving. Overall, intensive agricultural systems with private irrigation systems seem more vulnerable and unsustainable and therefore the extension of public irrigation systems and semi-intensive agriculture is recommendable to improve the sustainability of agriculture in this arid zone.

Keywords: *Irrigated agriculture; Water policy; bio-economic model; Integrated assessment*

1. Introduction

Land degradation is one of the most important environmental externalities of today and a major threat to the sustainability of agricultural systems in developing countries. The Oum Zessar watershed, in the south of Tunisia, represents an example where land degradation and overexploitation of water resources are serious problems. The pressure on natural resources in this region is increasing in the last decades due to agricultural intensification, increase in human needs and the opening to regional markets. The situation may get worse over the years, especially with climate change and further intensification of agricultural practices, if no concrete measures are taken. Land use policies are one of the most important factors that have a role to internalize this externality and ensure the sustainability of farming systems in arid regions (Tilman et al, 2002). It was assumed that the water policy is one of the land use policies that may have an important role to reduce these problems and its impacts on agricultural activities, especially on the demand of irrigation water. Another hypothesis, the intensification in agriculture can lead to overexploitation of water resources more than the realization of profitability economic for the farm.

Water saving irrigation in arid areas is an important factor for the sustainability of agricultural systems. For the last two decades, the water policy in Tunisia has managed and regulated water demand based on a price policy for irrigation water. The objective of this paper is to assess, ex-ante, the impacts of a water pricing policy on the farming system in the watershed of Oum Zessar.

2. Overview of water policies in Tunisia

From the sixties to the eighties, water management policy concentrated on the mobilization of water resources and the implementation of required infrastructure for the distribution of these resources all over the country. This has contributed to the expansion of irrigated areas, intensification, diversification and regulation of the agricultural systems.

In the beginning of the nineties, water management had to change its focus as this period has been marked by the development of the industrial and tourism sectors as competitors to the traditional water consuming sector. In addition, demand for water in agriculture increased as a result of newly created areas and intensification efforts. The total demand for water has increased substantially. Therefore, the new water policy introduced in the nineties has turned to the management and regulation of demand, while continuing the effort of water mobilization (Bachta et al., 2004). The main objective for this new policy is to conserve water resources and encourage demand management in the irrigation sector; a national water saving strategy was implemented. As part of this strategy, a number of reforms were introduced in the past few years, including the promotion of water users' associations, called locally "*Groupements de Développement Agricore,* (GDA)", an increase in the price of irrigation water was used for pushing the farmers to adopt technologies that increase water use efficiency at field level. This strategy has sought to rationalize the pricing of irrigation water in terms of (i) costs, (ii) variations among systems, and (iii) national priorities, notably food security (Fouzai and Zekri, 2002; Al Atiri, 2005).

Since 1990, the price of irrigation water has increased gradually at an annual rate by 13% in real terms to cover full cost of operating and maintenance. In 2007, the water price in public irrigation systems at the Oum Zessar watershed was in the range of 0.08 TD[1] per m^3. Assessing the impact of this policy options was subject only to ex-post evaluation in several regions of the country. These ex-post evaluations showed that the

[1] TD: Tunisian Dinars; 1DT=0.56 € = 0.77US$ in 2007.

increase in price has resulted in full recovery of operating costs, a significant drop in water consumption and a change in land use by irrigated crops in some regions of Tunisia. In the central, western and northeastern regions however, with large areas of high value crops (fruits, vegetables and greenhouses crops), water demand remains relatively inelastic and income is reduced (Hamdane, 2002). These results are useful to analyze past situations but they must also be used to improve the situation for the future through the suggestion of new policy options. The results of a change in the past cannot directly be extrapolated to the future however. On the other hand, ex-ante impact assessment of the water pricing is still underdeveloped in the research and evaluation projects conducted by the Ministry of Agriculture and Water Resources. Today, the need to develop modelling tools for the ex-ante impact assessment of policy options becomes a necessary methodological and pragmatic approach to improve the agricultural sector in Tunisia. This paper represents an ex-ante impact assessment of the water pricing policy on the sustainability of farming in the arid south-east of Tunisia. The bio-economic modelling approach has been mobilized for this impact assessment.

3. Methodology and area of study

3.1. The bio-economic modelling approach

The bio-economic modelling approach is known generally as a linkage between models from different disciplines to provide multi-disciplinary and multi-scale answers to a given problem. Bio-economic models provide a comprehensive indication on the relationship between human activities and environmental externalities and take into account simultaneously the technical, economic and environmental impacts of policies, without having to give a monetary value to environmental aspects (i.e. environmental indicators are expressed in physical terms). At farm level, these types of models are referred to as bio-economic farm models. A bio-economic farm model is defined as a model that links formulations describing farmers' resource management decisions to formulations that describe current and alternative production possibilities in terms of required inputs to achieve outputs and associated externalities. In many studies, bio-economic farms models have been proposed as tools to assess the impacts of policy changes on agricultural systems (Donaldson et al., 1995; Flichman, 1996; Riesgo and Gomez-Limon, 2006; Semaan et al., 2007). As mentioned above however, most models were developed for specific contexts, and data needs were often large, causing that it was difficult to re-apply these models for different contexts. This study uses a generic bio-economic farm model and adapts, applies and tests the model for use outside the original context. This generic model is the Farming Systems Simulator (FSSIM) developed in the SEAMLESS project. The SEAMLESS project (System for Environmental and Agricultural Modelling: Linking European Science and Society) developed an integrated framework for assessment of the agricultural sector targeted at assessing agricultural and environmental policies and technological innovations at multiple scales (Van Ittersum et al., 2008). The study presented in this paper is part of the LUPIS project (Land Use Policies and Sustainable Development in Developing Countries), which is a cooperation between European and developing countries aiming to adapt generic models developed for the European context and apply them for new research questions in developing countries. The main objective of the LUPIS project is to ex-ante analyzes the impacts of land use policies on sustainable development, comparing a range of developing countries. The different methods and tools developed in SEAMLESS project can be applied for this objective. The bio-economic farm model FSSIM is specifically suitable for assessment impacts of land use policies at farm level in same case studies in Lupis project.

This article has two objectives: The first objective is to adapt this generic bio-economic farm model FSSIM to a context different from the original European context, where the water pricing policy in Tunisia serves as an example for other developing country contexts. The second objective is to assess, ex-ante, the impacts of a water pricing policy on the farming systems in the watershed of Oum Zessar in southeastern Tunisia.

3.2. Case study: Oum Zessar Watershed

The Oum Zessar watershed is located in the Northwestern Governorate of Médenine and covers 36530 ha (Figure 1). It stretches from the mountains of Matmata (*Beni khédache*) in the south-west, crosses the Jeffara plain (*via Koutine*) and the saline depression (*Sebkha*) before ending in the Mediterranean (Gulf of Gabes). The choice for this watershed was made due to its geographical situation and its hydrological, ecological and socio-economic functions. It has a strategic importance in terms of water resources. Approximately 70% of this potential resource is mobilised. Agriculture is the largest water-consuming sector (using 84% of water consumed), followed by domestic use (13%). Industry, tourism and various other sectors make use of the remainder (Mamou, 1977). It also has a high socio-economic importance with its agricultural sector. This importance is explained by the annual income of the agriculture sector at the regional level that exceeds 120 Million Tunisian dinars and provides employment to one fifth of the working population (MEDD, 2006).

The farming systems are marked by their diversity from the upstream to downstream areas of the watershed. The systems are characterised by the predominance of olives trees, agricultural activities that vary from one year to another depending on the rainfall

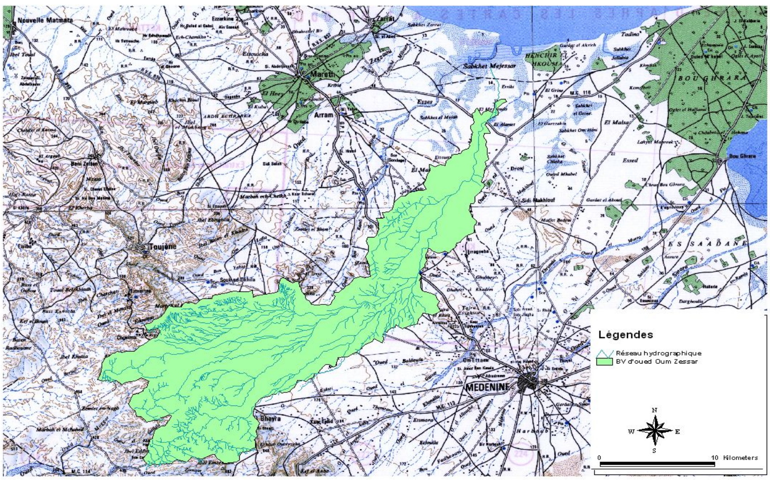

Figure 1: *Location of Oum Zessar watershed.*

regime, the development of irrigated agriculture exploiting the shallow and deep groundwater aquifers of the region, and the development of episode cereals.
Irrigated agriculture can be distinguished by two types of irrigation systems. Firstly, the private irrigation system which is based on private wells at the farm level, and it is mainly localized in the upstream area of the watershed (at *Ksar Hallouf*), with some in the downstream areas. Land use includes cash crops, greenhouses, vegetables and fruit trees. The cropping area varies between 0.2 and 10 ha per farmer. Secondly, the public irrigation system is based on collective drilling, usually created by the government. The water management is ensured by different Groups of Agricultural Development (*GDA*). These areas are situated in the downstream zone of the watershed, and include the public irrigation systems of "*Oum Zessar*", *"Oued Moussa"* and *"Gosba"*.

3.3. Bio-economic model FSSIM

FSSIM is an optimization model which maximizes a farm's total gross marginal subject to set of resource and policy constraints. Total gross marginal is defined as total revenues minus total variables costs from crop. Total variables costs include costs of fertilizers, costs of crop protection, costs of seed and plant material, costs of hired labour and costs of irrigation water. A quadratic objective function used to account increasing variable costs per unit of production because of inadequate machinery and management capacity and decreasing yields due to land heterogeneity (Howitt, 1995). The general mathematical formulation of FSSIM is presented below (Equation1) (Louhichi et al, 2010):

$$\text{Maximize:} \quad Z = W'X - X'QX$$
$$\text{Subject to:} \quad Ax \leq b;\ x \geq 0 \qquad (1)$$

Where Z is the total gross marginal, W is the (n x 1) vector of the parameters of the linear part of the activities' gross marginal, Q is the (n x n) matrix of the parameters of the quadratic part of the activities' gross marginal, X is the (n x 1) of the simulated levels of the agricultural activities, A is the (m x n) matrix of the technical coefficients and b is the (m x1) vector of available resources levels.

The agricultural activities are defined in FSSIM as a combination of crop rotation, soil type, irrigation technique and the production system. The livestock activities are not considered in this bio-economic modelling; because of missing data required to run the model and get good results, we preferred therefore to study the impact of water pricing on agriculture system as a first attempt to adapt this bio-economic model outside the European context, but in the future research, it is important to integrate the livestock activities to assess a set of agricultural policies for whole activities (agricultural and livestock).

The principal technical and socio-economic constraints are implemented in FSSIM: arable land, irrigable land, area of perennials activities, labour and water constraints. The available arable land constraint is specified per soil type and ensures that the sum of the area of the activities on a certain soil does not exceed the available farm land for this soil type. The available land is derived from data survey and hence imposed exogenously. Selling or buying of land is not considered in FSSIM. The available irrigated land constraint ensures that the area with irrigated activities does not exceed the available irrigable land. The area of perennials activities (i.e. olive trees) is not simulated but included as a constraint, as perennial activities are determined by long-term investment decisions. It is assumed that the levels of these crops are equal to the ones observed in the base year. The available amount of irrigation water constraint ensures that the total volume of water required for the irrigated activities does not exceed the available water volume. Finally, the labour constraint is used to calculate the number of hours of hired labour, given the labour requirements of different activities and the availability of family labour. Hired labour is considered as an additional cost, the price of which is equal to the average region-specific wage rate. Allocation of family labour to off-farm activities is not considered in FSSIM.

3.3.1. Calibration model

FSSIM is a positive model, which means that it reproduces the observed levels of the base year, and uses these to forecast future changes. In our application, the standard Positive Mathematical Programming approach developed by Howitt (1995) was used to calibrate the model and to guarantee exact reproduction of the observed situation. The standard PMP approach is a generic and fully automated procedure which means that it can be easily adapted and used in different regions and farm types without additional specific information.

In PMP calibrated models, the observed activity levels of farm types are used to calculate the non linear cost function (Kanellopoulos et al., 2010). The standard approach of PMP uses a two step approach. In the first step, a number of calibration constraints are added to the model, to ensure that the observed activity levels of the base year are reproduced. In the second step, the calibration constraints are taken out and their shadow prices are used to specify and include the non-linear costs in the objective function. This approach has been applied in many European researches for evaluating Common Agricultural Policy's reform impacts.

3.3.2. Policy scenarios simulated by FSSIM

At the farm level the main policy option that was assessed is related to the irrigated water pricing. To implement the irrigated water policy, assumptions need to be made on how the policy or the policy parameters change and assess their impact on the farming systems (Jeder et al, 2011). Four scenarios have been assessed using the FSSIM model, including two policy scenarios:

***Base year**:* the base year for the calibration is 2007, and the simulation is based on data on current cropping patterns, inputs and outputs

***Baseline scenario**:* the baseline serves as the reference for the policy scenarios in 2015. The assumptions for the baseline scenario are the following: (i) an inflation rate of 2.9% for all inputs and outputs (based on the central bank statistics of Tunisia); (ii) prices and and yields of crops follow a statistical Gaussian distribution[2].

***Policy option 1**:* an increase of the irrigation water price for the next years at an annual rate of 13%, from 2007 and 2015 for the farms in the public irrigation systems.

***Policy option 2**:* an increase of the cost of pumping irrigation water for the next years at an annual rate of 13%, from 2007 to 2015 for farms in the private irrigation systems.

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[2] Yields and price trends are not considered in this application.

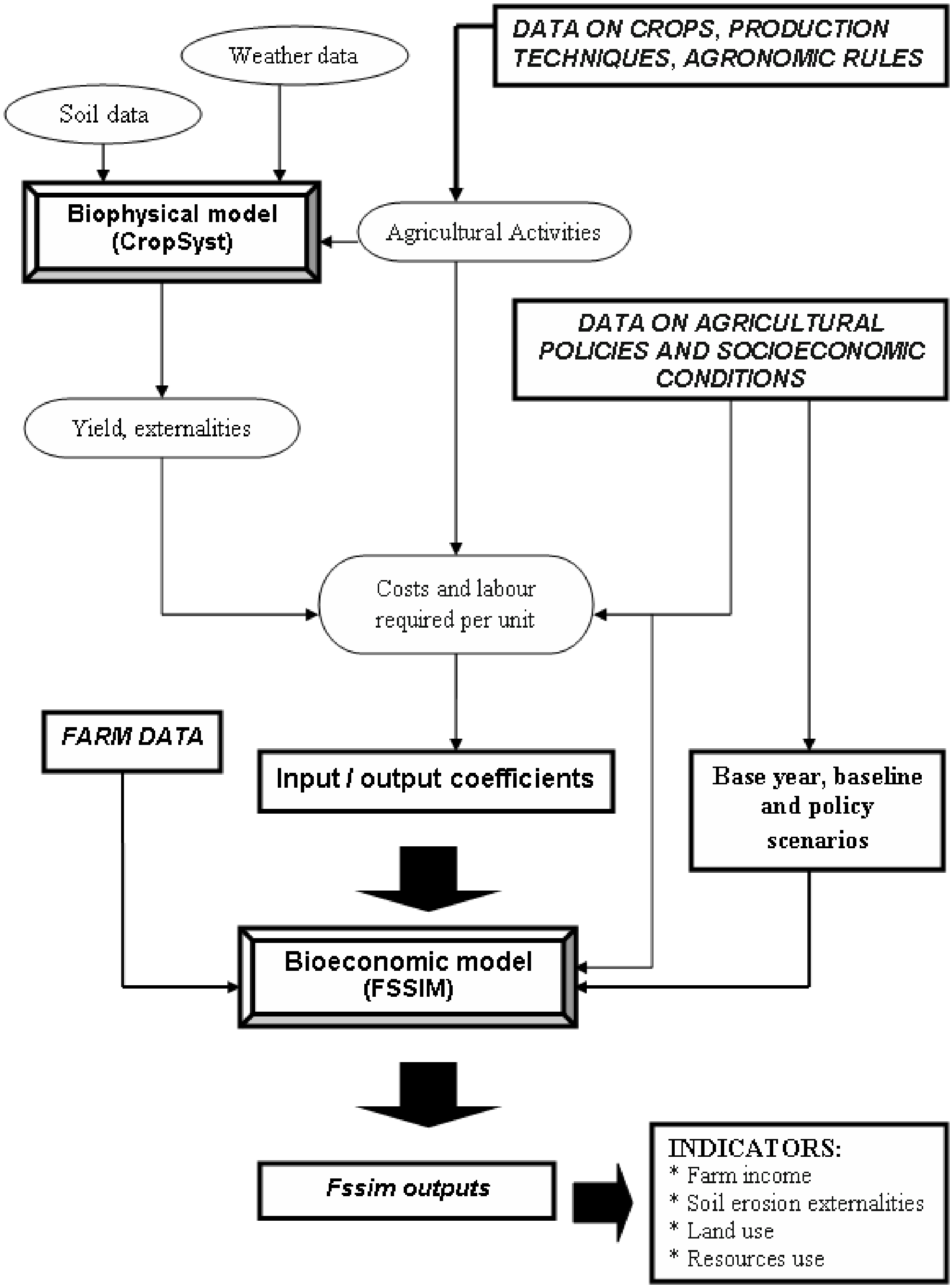

Figure 2: *Inputs and outputs of the model chain CropSyst-FSSIM as applied in Oum Zessar watershed.*

3.3.3. Environmental externalities

For parameters on externalities, the biophysical model CropSyst (Stöckle et al., 2003) has been used to calculate the externality 'soil erosion'. Most bio-economic modelling work in Tunisia used CropSyst to assess environmental indicators (Belhouchette, 2004; Abbés, 2005), in Europe also, it was used for FSSIM applications in framwork of SEAMLESS project (Belhouchette et al., 2011). The calculation of soil erosion is based on the widely used Wischmeier and Smith equation (*USLE* Universal Soil Loss Equation). According to this model, erosion is a multiplicative function of ***R*** (rainfall and runoff factor by geographic location), ***K*** (soil erodibility factor), ***LS*** (slope length-gradient factor), ***C*** (crop/vegetation and management factor) and ***P*** (support practice factor) (Equation 4):

$$\text{Universal Soil Loss Equation (USLE): } A = R * K * LS * C * P \qquad (2)$$

To apply the CropSyst-FSSIM model chain, three types of data are required: (i) the bio-physical characteristics of the agri-environmental zones used as input for the bio-physical model CropSyst, (ii) the farm type characteristics used in FSSIM to define the resources availability, and (ii) the input output data/coefficients of the current activities which include technical, social and economic information such as yield, input, prices and costs (Figure 2).

3.4 Data acquisition

3.4.1. Farm data

This research took particular care to gather high-quality data on the technical and economic systems employed by the individual farms. Information concerning the quantities of input used per crop and crop yields were gathered through a targeted survey with 50 farms in the watershed, of which some were part of the regional agriculture advisory services. These data have been collected for the most frequent cropping system in the region. They take into account cropping techniques, rotation and climatic conditions. As not all farms can be simulated individually, a farm typology was developed grouping similar farms, and data was aggregated per farm type.

The methodological approach adopted for developing a farm typology was not based on a statistical approach, but criteria were developed based on the survey and interviews with farmers and experts in the region and a literature review on the production systems in the region. This approach resulted in two major criteria: criterion (1) is type of irrigation system, public or private; criterion (2) is the size of farms. To better specify the production systems identified, an additional secondary criterion was developed, which is the ratio of irrigated and irrigable land within a farm indicating the degree of intensification. This methodology resulted in four farm types (Figure 3); a large semi-intensive farm in the public irrigation system (farm 1), a small intensive farm in the public irrigation system (farm 2), a large semi-intensive farm in the private irrigation system (farm 3), and a small intensive farm in the private irrigation system (farm 4).

Each farm type identified represents a virtual farm obtained by averaging data from farms that are grouped in the same type. From Table 1, it is possible to extract the data on resource endowment of each farm type, such as available land per soil type (%), irrigation water availability (m^3), water price (DT/m^3), area crops (%) and family labour

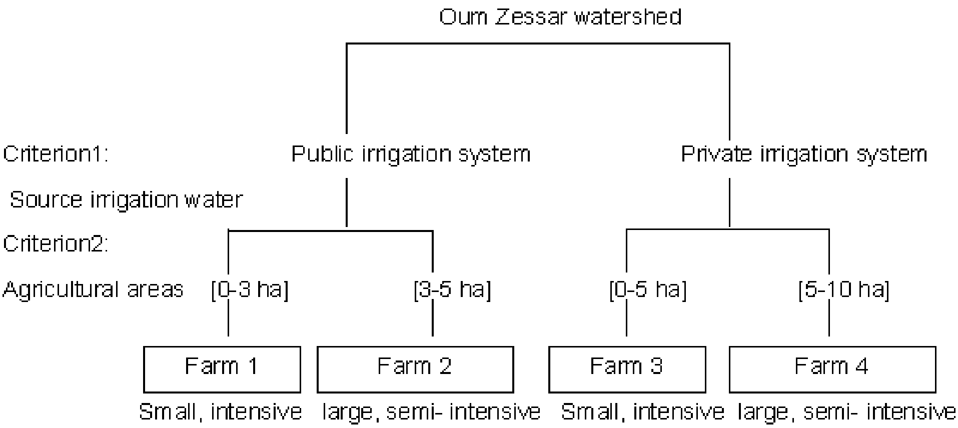

Figure 3: *Typology of farm types selected*

Table 1. *Main characteristics of the arable farm types in the Oum Zessar watershed.*

Irrigation system	**Public irrigation system**		**Private irrigation system**	
Farm types	**Farm 1**	**Farm 2**	**Farm 3**	**Farm 4**
Size	Small	Large	Small	Large
Intensity system	Semi-intensive	Intensive	Semi-intensive	Intensive
Area by farm (ha)	3.5	2.5	6.44	3.02
Irrigable area by farm (%)	1.95 (56%)	2.1 (84%)	3.95 (50%)	2.4 (56%)
Area Soil types[a]				
S1: Fluvisols	15%	30%	17%	10%
S2: Rebdzinas	25%	30%	3%	17%
S3: Xerosols	60%	40%	80%	74%
Available water (m^3)	6719	8095	18438	10174
Available labour (hours)	975	650	1525	1120
Price of water (DT/m3)	0.08	0.08	0.236	0.256
Cereals area (%)	14.6	8.8	11.65	5.95
Vegetables area (%)	20.6	29.6	54.8	38.1
Forage area (%)	6.9	12.0	2.5	11.9
Fallow area (%)	6.9	4.4	7.6	5.3
Olive area (%)	51.2	45.2	23.5	38.8

Source: Survey data (2007)

availability (hours/year). These data were used to define Right Hand Side (RHS) constraints values as well as the observed crop pattern used for the calibration.

3.4.2. Crops

The irrigated crops in the Oum Zessar watershed that were considered in this study include potatoes, pumpkin, tomatoes, pepper and cucumber, and the forage crops alfalfa and oats. Rainfed crops are durum wheat and barley. With regard to tree crops, olive is the most cultivated in this area.

Table 2: *Set of input and output coefficient for current agricultural activities in the Oum Zessar watershed.*

Rotation	Crops	Soil	Techniques[a]	Yield (ton/ha)	Yield variability (%) (2005-2008)	Labour (hours/ha)	Water use (m^3)	Variable costs (DT/ha)	Soil erosion (ton/ha) [b]	Average price (DT/ha)	Price variability (%) (2005-2008)
Fallow	Fallow	S1	Tr	0	0	3	0	50	12	0	0
Fallow	Fallow	S2	Tr	0	0	5	0	50	6	0	0
Fallow	Fallow	S3	Tr	0	0	8	0	50	3	0	0
Oates	Oates	S3	Ti	0	0	424	8000	824	6	350	15
Alfalfa	Alfalfa	S2	Ti	35.57	9	595	12000	2095	0	300	10
Olive	Olive	S1	Tr	0.87	12	40	0	190	0	883	20
Olive	Olive	S1	Ti	1.4	5	60	1700	325	0	883	20
Olive	Olive	S2	Tr	0.77	18	30	0	150	0	883	20
Olive	Olive	S2	Ti	1.18	8	60	1850	325	0	883	20
Olive	Olive	S3	Tr	0.65	30	35	0	140	0	883	20
Olive	Olive	S3	Ti	1.57	8	60	2000	325	0	883	20
Barley	Barley	S1	Tr	0.52	25	50	0	90	3	337	25
Potatoes-Pumpkin	Potatoes	S3	Ti-Ti	12.89	5	1500	6000	2337	3	482	15
Potatoes-Pumpkin	Pumpkin	S3	Ti-Ti	25.44	6	1600	4500	1536	3	440	10
Tomatoes -Cucumber	Tomatoes	S3	Ti-Ti	19.71	17	850	3500	2035	3	543	15
Tomatoes -Cucumber	Cucumber	S3	Ti-Ti	25.11	12	750	5000	1536	12	562	10
Durum wheat -Barley	Durum wheat	S1	Tr-Tr	1.07	25	120	0	135	6	463	35
Durum wheat -Barley	Barley	S1	Tr-Tr	0.57	15	50	0	90	12	337	25
Barley- Pepper	Barley	S3	Tr-Ti	0.55	10	65	0	110	12	337	25
Barley- Pepper	Pepper	S3	Tr-Ti	20.87	16	800	5500	2120	3	985	15

Source: survey and regional data, and own calculations

a. Production techniques: Tr: rainfed and Ti: irrigated. For example, the notation “Ti-Tr” means the first crop is irrigated “Ti” and the second crop is rainfed.

b. The biophysical model used is not yet able to simulate the erosion generated by "olive"; it was assumed that the olive tree is not degrading soils, this coefficient equal to zero.

Main current rotations identified were tomatoes-cucumber, barley-pepper, potatoes-pumpkin and durum wheat-barley. Combined to management types, soil types and production system, these rotations define the current activities. For each crop within an agricultural activity a set of data was collected. It included data on average yield, yield variability, labour use, and amount and method of water management as presented in Table 2.

Additionally, for each crop a set of economic data has been specified including producer prices, water pricing, and variable costs. The average prices and variability were collected from regional data such as the Office of South Development (ODS, 2008), and data were averaged for 2005-2008 (Table 2). Variable costs were calculated by summing input costs (fertilizers, seeds and biocides), irrigation costs and hired labour costs.

4. Results

4.1. Model calibration

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 2007 (observed value). The difference between both values is assed 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 farm types are bigger than the fixed threshold which is 15%, showing that the model is not exactly calibrated. This is explained by the limited number of binding constraints and the lack of specification technologies (i.e. the only distinction is between rainfed and irrigated, not other irrigation techniques such as drip irrigation, complementary sprinkler irrigation for fruit trres). The second step by applying the method of Positive Mathematical Programming (PMP), the model is calibrated exactly (PAD is equal to zero). Once the model is calibrated, it can make the simulation scenarios.

4.2. Impact assessment of policy option 1: increasing of water pricing

The comparison between policy option 1 and the baseline in 2015 in Table 4 shows: (i) a decrease in water consumption due to the increased cost of production, (ii) a decline in hours of labour, (ii) changes in crop areas, and (iii) a reduced level of soil erosion for certain farm types. Increasing water price by 13% led to drop of water use of 17.6 % on the intensive farm 1, which is larger than the 14.9% on the semi-intensive farm 2.

The economic results show a larger decrease in income for the intensive farm 1 compared to the semi-intensive farm 2. The decrease reaches 7.6% for the intensive farm 1 explaining the importance of the input water for such agricultural practice. The irrigation water price increase has hugely contributed to the increase of the production cost. The drop in temporal labour could not compensate for this, while in the meantime it does affect social stability and the agricultural employment in the region.

Table 3: *Results of model calibration*

Irrigation system	**Public irrigation system**						**Private irrigation system**					
Farm types	**Farm 1**			**Farm 2**			**Farm 3**			**Farm 4**		
Farming system	**Small, intensive system**			**Large, semi-intensive system**			**Small, intensive system**			**Large, semi-intensive system**		
Crops	**Obs. level**	**Sim. BC[a]**	**Sim. AC[b]**	**Obs. level**	**Sim. BC[a]**	**Sim. AC[b]**	**Obs. level**	**Sim. BC[a]**	**Sim. AC[b]**	**Obs. level**	**Sim. BC[a]**	**Sim. AC[b]**
Barley	0.12	0.66	0.12	0.51	0.85	0.51	0.10	0.92	0.10	0.50	1.98	0.50
Durum wheat	0.10		0.10				0.08		0.08	0.25		0.25
Oats	0.05		0.05							0.05		0.05
Alfalfa	0.25	0.05	0.25	0.24		0.24	0.36		0.36	0.11		0.11
Potatoes										0.25		0.25
Tomatoes	0.36		0.36	0.10		0.10	0.57		0.57	1.39		1.39
Pumpkin										0.25		0.25
Pepper	0.02	0.66	0.02	0.51	0.85	0.51	0.02	0.92	0.02	0.25	1.97	0.25
Cucumber	0.36		0.36	0.10		0.10	0.57		0.57	1.39		1.39
Fallow	0.11		0.11	0.24		0.24	0.16		0.16	0.49		0.49
Olive	1.13	1.13	1.13	1.79	1.79	1.79	1.17	1.17	1.17	1.51	1.51	1.51
Total area	2.5	2.5	2.5	3.5	3.5	3.5	3.02	3.02	3.02	6.44	5.46	6.44
PAD without PMP		43.20			27.42			54.63			61.25	
PAD with PMP (%)			0.00			0.00			0.00			0.00

Source: model results

a: simulated area before calibration PMP

b: simulated area after calibration PMP

Table 4: *Impact of policy option 1-2015 (increase price of irrigation water) at the farm level.*

Irrigation system	**Public irrigation system**			
Farm type	**Farm 1**		**Farm 2**	
Farming system	**Small, intensive**		**Large, semi-intensive**	
Indicators /Units	**Baseline 2015**	**Policy option 1-2015 (%)**	**Baseline 2015**	**Policy option 1-2015 (%)**
Farm income (DT/ha)	4171	-7.6	3880	-5.7
Total costs (DT/ha)	3318	+8.0	3026	5.8
Labour (Hours/ha)	883	-5.4	644	-7.1
Water use (m^3/ha)	3224	-17.6	1919	-14.9
Soil erosion (ton/ha)	3.30	-6.3	3.30	-6.8
Barley area (ha)	0.12	+17.4	0.61	+11.7
Durum wheat area (ha)	0.10	+8.7		
Oats area (ha)	0.05	+5.8		
Cereals area (ha)	0.27	+13.7	0.61	+11.8
Potatoes				
Tomatoes	0.43	+17.0	0.16	-4.8
Pumpkin				
Pepper	0.03	+45.3	0.61	+11.8
Cucumber	0.43	+17.0	0.16	-4.8
Vegetables area (ha)	0.89	+18.0	0.93	+6.1
Olive area (ha)	1.13	0.0	1.79	0.0
Forage : alfalfa area (ha)	0.25	-77.5	0.17	-75.0

Source: model results

The environmental externality soil erosion declines substantially for both farm types with 6.3% and 6.8 % for farm 1 and 2, respectively. This result can be explained by the change in the allocation of land between the rainfed and irrigated crops. The results (Table 4) showed an increase in area of (mainly rainfed) cereals with 13.7% for the intensive farm 1 and 11.8% for the semi-intensive farm 2 against a decline in area of the irrigated forage crop alfalfa by 77.5 % for farm 1 and by 75% for farm 2. Alfalfa requires a lot water and labor (Table 2) during all agricultural seasons. On farm 2, also the area of the vegetable crops tomatoes and cucumber decline by 4.8 % each, but the area of pepper increases by 11.8 %. On the intensive farm 1, the areas of all vegetable crops increase by 18 % on average. These strategies show that both farms reduce areas of most water demanding crops, but at the same time increase areas of irrigated crops that are most profitable.

4.3. Impacts assessment of policy option 2: increased cost of pumping water

The economic results in Table 5 show a larger decrease in income for the intensive farm 3 (24.9%) compared to the semi-intensive farm 4 (21.9%) after the decrease of water consumption to 11.1% for farm 3 and to 4.6% for farm 4. The significant drops in

Table 5: *Impact of policy option 2-2015 (increase cost of pumping water) at the farm level.*

Irrigation system	**Private irrigation system**			
Farm type	**Farm 3**		**Farm 4**	
Farming system	**Small, intensive**		**Large, semi-intensive**	
Indicators /Units	**Baseline 2015**	**Policy option 2-2015 (%)**	**Baseline 2015**	**Policy option 2-2015 (%)**
Farm income (DT/ha)	5452	-24.9	5266	-21.9
Total costs (DT/ha)	3369	+37.8	3604	+27.5
Labour (Hours/ha)	1069	-3.5	1070	-3.8
Water use (m^3/ha)	3360	-11.1	2863	-4.6
Soil erosion (ton/ha)	4.29	-3.2	4.83	-0.4
Barley area (ha)	0.10	+31.0	0.49	-0.2
Durum wheat area (ha)	0.08	+12.7	0.66	+20.6
Oats area (ha)			0.05	-5.8
Cereals area (ha)	0.18	+23.0	1.20	+11.0
Potatoes			0.25	+4.9
Tomatoes	0.66	+6.2	1.52	-8.9
Pumpkin			0.25	+4.9
Pepper	0.03	+50.0	0.17	+80.7
Cucumber	0.66	+0.7	1.52	-8.9
Vegetables area (ha)	1.35	+7.6	3.71	-3.0
Olive area (ha)	1.17	0.0	1.51	0.0
Forage: alfalfa area (ha)	0.32	-45.1	0.07	-37.1

Source: model results

farm income show that these types of agricultural system heavily dependent on the production factor ‘water’. To address the significant decline in profitability of the farm, farmers adopt various cropping strategies according to its constraints and its techno-economic conditions. The behaviors of these farmers are manifested by the decrease in hours of labour by 3.5% for the intensive farm 3 and 3.8% for the semi-intensive farm 4 (Table 5).

In terms of environmental impacts, policy option 2 shows that the decrease in water consumption for the intensive farm 3 reduces soil erosion (3.2%) generated by the effect of irrigation with saline water on fragile soils. For the semi-intensive farm 4 the impact is negligible.

In terms of agricultural area, Table 5 shows that forage area is already low on farm 4 in the baseline. Hence, this farm has relatively little opportunity to further reduce water use, and income is directly affected. It is the only farm type where vegetable area is reduced, despite the high profitability. The intensive farm 3 switches forage crops for vegetable crops (7.6%), especially pepper, which is more profitable in economic terms. But as this system is still based on irrigated crops, the income is also greatly reduced following the increase of water prices.

Table 6: *Sensitivity analysis, showing change in indicators due to increases in water price or pumping of water, relative to the baseline*

Increase price /costs pumping of water %		**Farm income (DT/ha)**		**Water consumption (m^3/ha)**		**Erosion (ton/ha)**	
		Farm 1	**Farm 3**	**Farm 1**	**Farm 3**	**Farm 1**	**Farm 3**
		Small, intensive	**Small, intensive**	**Small, intensive**	**Small, intensive**	**Small, intensive**	**Small, intensive**
S0	13 (baseline)	3795	4097	2655	2988	4.55	4.16
S1	14	-1%	-3%	-12%	-3%	0%	-1%
S2	15	-2%	-7%	-13%	-6%	0%	-2%
S3	16	-3%	-10%	-13%	-10%	0%	-3%
S4	**17**	**-5%**	**-14%**	**-13%**	**-13%**	**1%**	**-4%**
S5	18	-6%	-18%	-14%	-14%	1%	-3%
S6	19	-7%	-22%	-14%	-14%	1%	-2%
S7	20	-9%	-27%	-14%	-15%	1%	-1%

Source: model results

4.4. Sensitivity analysis

The CropSyst-FSSIM model chain can be used as decision tool for policy makers and local actors with regard to the water policy and the impacts on farming systems and the sustainability of irrigated agriculture in the region. This requires the comparison of different alternatives, and therefore a sensitivity analysis was performed.

The sensitivity analysis is based on the simulation of variation in prices and costs of irrigation water for the intensive systems (farm 1 and farm 3). The results in Table 6 show that when prices are increased with 20%, the intensive farm in the public irrigation system is able to absorb the impact with only an income decline of 9%. The decline in farm income in the private irrigation system on the other hand reaches 27%. In terms of environmental externalities, increasing water prices or the cost of pumping induces small reductions in soil erosion in both irrigation systems.

The sensitivity analysis also showed that increasing the water price with more than 17% (equals to 0.280 DT/m^3 for the public and 0.836 DT/m^3 for the private irrigation systems) is not advisable to local decision makers, because the net income continues to decline, while the water consumption remains stable with further increases. Hence, there is no further gain in terms of water saving. Overall, intensive agricultural systems with private irrigation systems seem most vulnerable and unsustainable regarding water use and therefore the extension of public irrigation systems and semi-intensive agriculture is recommendable to improve the sustainability of agriculture in this arid zone.

5. Discussion

5.1. Impacts of water pricing policy on agricultural activities

This study showed that a water price increase of 13% leads to a reduction in water consumption in all farms types, particularly the intensive farms. This result is similar to other empirical studies (Gomes and Berbel-Limon, 2000; de Fraiture and Perry, 2002), showing that the pricing policy remains an effective instrument to control the consumption of water in agriculture. The significant drops in farm income show that the agricultural systems in Oum Zessar watershed heavily dependent on the production factor 'water'. Independent of the policy, pumping costs will increase due to the decline in groundwater level. This, along with the instability of natural conditions, in particular climate change and difficult conditions in the international energy market, affects the economic viability of these farms types in the coming years. To address the significant decline in profitability of the farm, farmers adopt various cropping strategies according to its constraints and its techno-economic conditions. These adaptations cannot completely reduce the negative economic impacts, but their impacts on the environment, water saving and reducing erosion, are positive. The degree of sustainability and vulnerability of each system to increased costs of irrigation water differ. This study showed that especially farms with private irrigation systems have few opportunities to adapt cropping patterns, and are therefore vulnerable to changes in external factors like policy, climate and the market.

An effective water pricing policy should have three objectives: water savings, limiting welfare losses and the collection of revenue. The objective to set charges at full- or near to-cost recovery prices has been at the core of most pricing reforms. In Tunisia, it is preferable to increase the price of water to encourage farmers to reduce waste and to ensure the transfer of welfare to the GDA (who determines the water price) to be used for repairs or to increase the production capacity of water in the next year. Irrigation water demand functions tend to be inelastic at low prices and more elastic at high water prices. Below a certain threshold of water prices, ratios of collected revenue and water savings over welfare losses are efficient, and when prices are inelastic any pricing change fall within the limits of farmers' "ability-to-pay". The price threshold can be identified if the water demand is estimated for a sufficiently wide price range (Iglesias et al., 1998), which resulted in a threshold of 17% price increase in this case study. Beyond this threshold, welfare losses increase while water use does not decrease anymore. Other secondary effects may occur, including resorting to fallow land and less profitable dry-land regimes.

5.2. Strength and weakness of Bio-economic farm model FSSIM

The bio-economic farm model FSSIM proved to be a good tool to assess land use policies like the case of the water pricing policy in Oum Zessar watershed in Tunisia. Simulation of a series of scenarios in combination with sensitivity analyses led to important recommendations for policy makers. The tool is generic enough to be applied in a different context, although some adaptations need to be made according the objective of their implement, for example, this model has been adapted also in china for integrated assessment of agricultural land use policies on nutrient pollution and sustainable development in Taihu Basin in the east of china in Lupis project (Reidsma et al., 2012).

It should be noted however that this application has some limitations in terms of methodology and assumptions. First of all, the application was limited to current observed activities. No improved activities such as improved irrigation techniques or alternative activities were included. Also livestock activities were not included, which could be relevant in relation to the forage crops. Including these would give farms more options to adapt to land use policies. However, the impact assessment focuses on the short term, 2015, so it can be assumed that there are not many alternatives available.

A second limitation is that it was assumed that the area of perennial crops remains constant. Perennial activities respond differently to price changes than annual activities due to long-tem investments. This is a restrictive assumption as olive trees are very important in all farm types. Olive trees do however not require much water, so water demand is virtually inelastic at low prices. The majority of olives trees are rain-fed, often behind the soil and water conservation works where rainwater is collected. In addition, water prices need to be substantially increased in order to achieve water savings and to encourage farmers to change crops when they cultivate high value crops such as olives, citrus and vegetables (Giannoccaro et al., 2009). Lastly, the fact that this is an impact assessment on the short-term is another reason to assume that perennial activities will remain constant.

6. Conclusion

The objective of this study was to perform an ex-ante impact assessment of the water pricing policy on four representative farm types of irrigated agriculture in the region in two different irrigation systems (a semi-intensive and intensive farm in the public irrigation system and a semi-intensive and intensive farm in the private irrigation system). This was done using the bio-economic model FSSIM coupled to the biophysical model CropSyst. Results showed the higher vulnerability of farms with private irrigation systems compared to farms in public irrigation systems facing scenarios of increased prices/costs of irrigation water by 13%. A sensitivity analysis showed that it is not advisable to policymakers to increase the price of irrigation water beyond a rate of 17% because the consumption of water does not further diminish, while the farm income continues to decrease tremendously. The sensitivity analysis also confirmed that the public irrigation system is more durable than the private irrigation system and the strategy of the Tunisian government to extend the public irrigation system is an appropriate strategy for the preservation of water resources and limit the problem of land degradation for sustainability of irrigated agricultural in arid zones.

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