Economic analysis of water demand in public irrigation systems in Tunisia, using FSSIM model

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Abstract

Water resources in dry areas in Tunisia are under strong pressure, which seriously threatens their sustainability. This situation may get worse over the years, especially with the climate change and the intensification of agricultural practices, if the concretes measures are not taken into account. Water pricing has been a key of the water policy in Tunisia for the last two decades to saving water. It depended on the characteristics of the irrigated farming in these dry areas. The objective of this paper is to assess the impact of water-policy on water demand for the farming in three different public irrigated systems. Bio-economic model, such as Farming System SIMulator (FSSIM), has been applied for this impact analysis. The main results from the analysis of the demand curve show that the flexibility of the crop plan and competition between irrigated crops are linked to the land constraint, in particular irrigable land. These results show also that the determination of an incentive price for the use of new irrigation technologies is located on the segment where the function of the demand is elastic. In this segment, the farmer's behavior becomes more rational to save water in arid zones like in the south of Tunisia where the water is a limiting factor for the irrigated agriculture.

Keywords: *irrigated land; water pricing, bio-economic model, impact analysis, water demand.*

Résumé

Les ressources en eau dans les zones arides de la Tunisie sont sujettes à de fortes pressions qui menacent sérieusement leur durabilité. Cette situation risque de s'aggraver au fil des années avec les changements climatiques et l'intensification de la pratique agricole. La tarification de l'eau demeure l'un des instruments de régulation le plus utilisé en matière d'économie d'eau au cours de ces dernières décennies. L'objectif de ce papier est d'apprécier, à travers une étude de cas, l'impact de la politique de tarification de l'eau d'irrigation sur la demande en eau pour l'exploitation agricole dans trois différents périmètres publics irrigués. Le modèle bioéconomique FSSIM «Farming System SIMulator» a été appliqué pour cette analyse d'impact. Les principaux résultats de l'analyse de la courbe de demande en eau d'irrigation montrent la flexibilité de plan d'occupation du sol par les cultures et la compétitivité entre les cultures irriguées qui est contrariée par la disponibilité de la terre, en particulier la terre irrigable. Les résultats montrent aussi que la détermination d'un prix incitatif pour l'utilisation des nouvelles technologies d'économie d'eau d'irrigation est localisée dans la partie du segment élastique de la courbe de la demande. Dans cette partie du segment élastique, le comportement de l'agriculteur devient plus rationnel pour mieux économiser l'eau d'irrigation, en particulier en ces zones arides comme le sud tunisien, où l'eau est un facteur limitant pour l'agriculture irriguée.

Mots clés: terre irriguée, tarification de l'eau, modèle bioéconomique, analyse d'impact, demande en eau.

1. Introduction

In Tunisia, irrigated agriculture represents 35% of the output value derived from the agricultural sector, 20% of exports and 27% of agricultural employment. Irrigated areas contribute 95% of the plant production, 70% of the fruit and 30% of the dairy (Ministry of Agriculture and Water Resources, 2003). For these reasons, policy makers are interested to develop the irrigated agriculture on the majority of the Tunisian territory through its importance in ensuring food security and its contribution to social welfare of farmers particularly in the rural area.

Tunisia has 411.4 thousand hectares of irrigated land. Tree crops come first, with an area of 152.6 thousand ha (37% of the total surface), vegetables second (30%), followed by forages (16%), cereals (16%), and other industrial crops (1%). The industrial and tourism sectors use 5% and 1% of water resources, respectively. The drinking water service uses 11% in the rural area (Dhehibi *et al.,* 2007). But the expansion of irrigated agriculture, the intensification and competitive sectors have led to the overuse of the majority of groundwater in Tunisia. Taking into account the limited water resources and the frequent disparity between supply and demand during dry seasons, Tunisia has engaged in the recent years on a program of sustainability management of water resources. The objective of this program is to save water potential in all economic sectors particular in the agricultural sector. The next paragraph presents a brief overview of water policies in Tunisia.

2. Overview of water policies in Tunisia

During the first period, water management policy concentrated on the mobilization of water resources and the implementation of required infrastructure to the distribution of these resources all over the country. This has contributed to extend irrigated areas, intensify, diversify and regulate the agricultural systems. The second period of water management has been marked by the development of the industrial and tourism sectors as competitors to the traditional water consuming sector (Al Atiri, 2004). Agriculture in addition to increased demand for water is a result of newly created areas and intensification efforts. The demand for water has increased substantially. Therefore, the new water policy has

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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 the strategy, a number of reforms were introduced in the past few years, including the promotion of water users' associations known as the "Grouping of Agricultural Development", called locally 'GDA', an increase in the price of irrigation water, and the use of incentives to adopt water technologies 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.

Since 1990, policy makers have adopted a strategy based on the gradual increase of prices of irrigation water at a rate between 9% and 15% in real terms and by region. This increase aims to recover the total cost of water mobilization (Al Atiri, 2005). But assessing the impact of this policy option was subject only to ex-post evaluation in several regions of the country. However, the objective of ex-ante impact of the water pricing is still very underdeveloped in the research and evaluation projects conducted by the Ministry of Agriculture and Water Resources.

Water pricing remains the most economic instrument used to reinforce users' participation in cost management and to provide incentives for the adoption of water saving techniques; however, the evaluation of their impacts on the sustainability of irrigated agriculture has several discussions on the degree of viability of this instrument to find a compromise between the sustainability of irrigated farming system and preservation of water resources in areas where scarcity of water resources is a key challenge for agricultural and sustainable development. Therefore the objective of this paper is to assess the impact of water-policy on the water demand of the farm and the determination of an incentive price for the use of new irrigation technologies. Our methodology based on the bio-economic modelling approach has been mobilized for this impact analysis.

3. Methodology and area of study

Our methodology is based on the FSSIM model (Farming System SIMulator model), it 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), wish to target integrated assessment of agricultural systems in the European Union.This implies that FSSIM can be and has been linked to other models for multi-scales analyses (Pérez Domínguez *et al.,* 2009).

3.1. FSSIM model

FSSIM is a generic bio-economic farm model which can be applied in the combination with the higher level models to assess farm level impact of future policy scenarios for different farm types in different regions. It 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 and minus total variable costs from crop production (Louhichi *et al.,* 2010). Total variable costs include costs of fertilizers, costs of irrigation water, costs of crop protection, costs of seeds and plant material and costs of hired labour. A quadratic objective function is used to account for 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:

$$\text{Maximise: } Z = w'x - x'Qx$$
$$\text{Subject to: } Ax \leq b;\ x \geq 0 \qquad (1)$$

Where Z is the total gross margin, w is the n x 1 vector of the parameters of the linear part of the activities' gross margin, Q is the n x n matrix of parameters of the quadratic part of the activities' gross margin, x is the n x 1 vector simulated levels of the agricultural activities, A is a the m x n matrix of the technical coefficient, and b is the m x1 vector of available resources 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). That is, an agricultural activity is a way of growing a rotation taking into account the management type. However, if data on crop rotations are missing, the agricultural activities can be defined using individual crops (i.e. mono-crop rotations).

The principal technical and socio-economic constraints that are implemented in FSSIM-MP are: arable land per soil type (or agri-environmental zone), irrigable land per soil type, labour and water constraints. The same rule was applied for all of these constraints: the sum of the requirements for each resource cannot exceed resource availability.

3.2. Adaptation of FSSIM for implemented water policy

FSSIM is able to simulate many agricultural and environmental instruments, some of which have already been implemented in practice while others might be of interest to policy makers in the future. These policies are modeled as additional constraints and variables in a generic way to account easily for various products or region-specific policy implementation.

The policy instrument that we intend to simulate is the pricing of water irrigation. This instrument has been modeled in FSSIM through the disintegration of the variable costs and including irrigation water costs in the expected income (Jeder *et al*., 2011). The analytical formulation of the irrigation water cost is presented below (Equation 2):

$$WC = \sum_i [cw_f + (cw_{pw} \cdot w_i \cdot x_i)] \qquad (2)$$

Where WC is the irrigation water cost, cw_f is the fixed water tariff based on the subscription to the public network connection for irrigation (Dinars/farmer), w_i is the amount of the water consumed (m^3), cw_{pw} means the price of water if the farm is connected to an irrigation public network and x_i is the level of the agricultural activities i.The inclusion of irrigation costs in the expected income is presented as follows (Equation 3):

$$Z = \sum_c p_c y_c - \sum_i vc_i \cdot x_i - \sum_i [cw_f + (cw_{pw} \cdot w_i \cdot x_i)] - PMP_{term} - c_{wage} \cdot T_{labour} \qquad (3)$$

Where p_c is the price of crop products (Dinars/tons), y_c is the average yield for each crop product, vc_i are the variable costs per crop with agricultural activity i (Dinars/ha), PMP_{term} is the Positive Mathematical Programming term (included to calibrate the FSSIM model), c_{wage} is the hired labour costs by hours(Dinars/hours), and T_{labour} the number of hours of hired labour.

3.3. Policy scenario

In this research, we seek to assess the impact of water policy on the irrigated farming system from three different Groups of Agricultural Development called locally by the (GDA) through an analysis of the water demand function derived from simulation of ex-ante impact assessment of Water pricing scenario (*Simulated price of water: to be parameterized from 0.40 to 0.340 DT/m^3)*

3.4. Area of study

We applied the FSSIM model to three different GDAs in southern Tunisia. We selected this GDA on the basis of availability of data and information:

1. Groups of Agricultural Development of Wadi Moussa called locally "GDA Oeud Moussa".
2. Groups of Agricultural Development of Oum Zessar called locally "GDA Oued Zessar".
3. Groups of Agricultural Development of Hezma called locally "GDA Amra".

The first GDA is located in the northern watershed of Oum Zessar. This area has been irrigated since 1990. It covers an area of 76 ha. Water salinity is approximately3g/l. Most irrigation is based on a gravity infrastructure. Water is distributed to the plots by plastic tubes. This irrigated area of Oued Moussa is an example of traditional mixed farming system based on rainfed and some irrigated crops. The irrigation is limited by the size of the farm and the ability of farmers to pay the cost of irrigation water. The current water price of water in this zone is 0.060 Tunisian Dinar (TD)/m3, which covers operating and maintenance costs.

The second GDAis located in the middle of Oued Zessar watershed. This area has been irrigated since 1990. It covers an area of 28ha. Water salinity is approximately2.5g/l. During 2004, this unit has been expanded to incorporate several farmers (32 farmers) due to the increased availability of water through the creation of new drilling water.The current water price of water in this zone is 0.080 Tunisian Dinar (TD)/m3, which covers operating and maintenance costs.

Finally, GDA of Amra was created in 1999. It covers an area of 50 ha. This is an example of intensive agriculture which consumes a lot of irrigation water. This unit is located downstream of Oum Zessar watershed. The current water price of water in this zone is 0.100 Tunisian Dinar (TD)/m3, which covers operating and maintenance costs.

4. Data acquisition

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 survey that target in the watershed. Prices for input and outputs are 2008 prices and were obtained from secondary sources (ODS, 2008). This information was complemented by direct questioning and cost accounting of farm belonging to the GDA.

4.1. Farm data

The farm data is obtained through the "*average*" farm. It is a virtual farm derived by averaging data from farms that were grouped in the same type. The farm groups were selected in each irrigation unit taking into account the heterogeneity in farming and biophysical endowment based on farm structure coming from the data survey and from publications and interviews with local agricultural extension services.

In Oum Zesaar watershed, three of the farm types have been selected as representative of the main arable farming system. The main characteristics and specification of these farm types are described in Table 1. From this table it could be possible to extract the data on resource endowment of each farm type, such as available land per soil type (%) and water irrigation availability measured in m^3, water-pricing (DT/m^3), area crops (%) and family labour availability (hours /year). These data are used to define constraints value RHS (Right Hand Side) as well as the observed crop pattern used for the calibration.

4.2. Crops

The irrigated crops in the Oum Zessar watershed that were considered in this study include potatoes, tomatoes, pepper and cucumber. The irrigated forage crop is based on alfalfa and oats. Rain-fed crops are durum wheat and barley. For tree crops, the olive is the most common in this area. Not all the crops are planted on the same farm

4.3. Inputs coefficients

A survey has been carried out in order to collect data on the current crop activities in the Oum Zessar watershed. Some local farmers, part of the regional agriculture advisory services, have been interviewed. These data have been collected for the most frequent cropping system in the region. They take into account cropping techniques, rotation and climate conditions.

Table 1 - *Main characteristics of the three farming systems in the different GDA.*

GDA	*GDA of Oued Moussa*	*GDA of OuedZessar*	*GDA of Amra*
Farming system	Mixed	Semi-intensive	Intensification
Area by farm (ha)	4.09	3.5	2.5
Irrigable area by farm (%)	42	56	84
Soil types (% of texture)	Fluvisoils (15%) Rebdzinas (26%) Xerosoils (59%)	Fluvisoils (15%) Rebdzinas (25%) Xerosoils (60%)	Fluvisoils (30%) Rebdzinas (17%) Xerosoils (53%)
Available water (m3)	6719.75	6159.74	8059.39
Available labour (hours)	725	975	650
Price of water (DT/m3)	0.06	0.08	0.10
Observed crop pattern (ha)	Area (ha)	Area (ha)	Area (ha)
Cereals	0.9	0.51	0.22
Vegetables	0.72	0.72	0.74
Forage	0.25	0.24	0.3
Fallow	0.41	0.24	0.11
Olive	1.81	1.79	1.13

Source: survey data.

Table 2 - *Results of model calibration.*

	GDA of Oued Moussa		*GDA of Oued Zessar*		*GDA of Amra*	
Farming system	Mixed		Semi-intensive		Intensification	
Crops	Obs. level (ha)	Sim. level (ha)	Obs. level (ha)	Sim. level (ha)	Obs. level (ha)	Sim. level (ha)
Barley	0.40	0.40	0.51	0.51	0.17	0.17
Durum wheat					0.10	0.10
Oates					0.05	0.05
Alfalfa	0.25	0.25	0.24	0.24	0.25	0.25
Tomatoes			-	0.10	-	0.36
Pepper			-	0.51	-	0.02
Cucumber	-	0.72	-	0.10	-	0.36
Vegetables*	0.72	0.72	0.72	0.71	0.74	0.74
Olive	1.81		1.79		0.11	0.11
Fallow	0.41		0.24		1.13	1.13
Total area	4.09	4.09	3.5	3.5	2.5	2.5
PAD without PMP (%)	10.53		13.71		37.34	
PAD with PMP (%)	0.002		0.002		0.008	

* The area of vegetables is the sum of these crops (tomatoes, Cucumber and Pepper).

Source: Model results.

The current rotation include tomatoes-cucumber, barley-pepper and durum wheat-barley. Combined to management types, soil types and production system, these rotations define the current activities. For each crop within agricultural activities a set of data were collected.

Additionally, for each crop a set of economic data has been specified including producer prices, water pricing, and variable costs. The average price and variability are collected from regional data based on 2005-2008. Variable costs are calculated by adding input costs without irrigation costs (fertilizers, seeds and biocides).The data of livestock activity is not included in this analysis because in this research we are interested in the farming system and the role of policy instruments for water saving. We used all this data to feed FSSIM for each farm type.

5. Results

5.1. 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 assessed statistically by using the percent absolute deviation (PAD)[1]. The results of the calibration without Positive Mathematical Programming (PMP) for the three farm type are presented in Table 2.

As shown in this table, the PAD obtained in the first step for the three 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. After the model has been calibrated for the three farm types (i.e. PAD equal to zero). The model can be used for simulation.

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[1] Percent Absolute Deviation «PAD» (%);

$$PAD = \frac{\sum_{i=1}^{n} \hat{x}_i - x_i}{\sum_{i=1}^{n} \hat{x}_i}.100$$

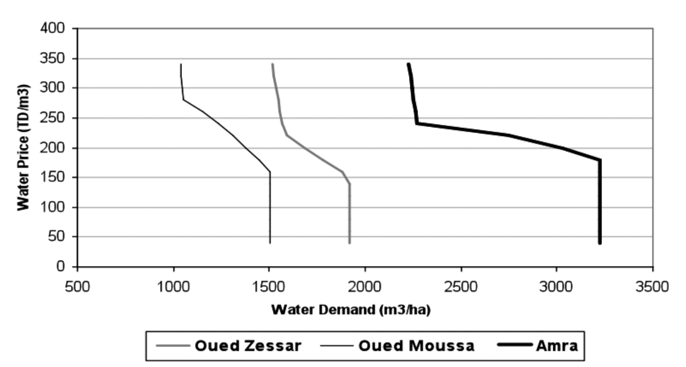
; Where $\hat{x}_i$ is the observed value of the variable i and x_i is the simulated value. The best calibration is reached while PAD is close to 0.

5.2. Impacts analysis of water pricing scenario at farm level

5.2.1. Water consumption

The impact of water pricing scenarios at farm levels (parameterized from 0.40 to 0.340 DT/m^3) helped construct the water demand for each farm types for different types of GDA. The results of these impacts are shown in Figure1.

Figure 1- *Irrigation water demand curve.*



This shows a classic demand curve that reflects farmers' adaptation to rising costs of production inputs. We see three different demand curves, which depend on specification farming system, climate conditions, soil and technical, environmental aspects. We can also discern same similarities that are relevant for policy making and which we want to emphasize. This finding was equally shown in other empirical studies (Berbel and Gomez-Limon, 2000; de Fraiture and Perry, 2002; Riesgo and Gomez-Limon, 2006; El Chami *et al*., 2011) (Table 3).

The segments are limited by water price values that differ for each GDA as shown in Table 7 below. We can divide the demand curve into three segments according to economic and technical characteristics defined below:

- Segment A (inelastic): the farmer makes a very small or zero response to price increases. He thus maintains this existing crop distribution and demand for water.
- Segment B (elastic): the farmer responds to price by reducing water consumption. He changes crops plan by growing crops that consume less water and the same not irrigated crops.
- Segment C (non efficient): demand is once again inelastic, and there is no or very small response to price increase.

This change in water consumption behaviour may be explained by changes in the crop, as an adaptation to the rising cost of water (Berbel and Gomez-Limon, 2000). The adaptation pattern may be seen in Table 4. When the price of water increases, the crops with high water consumption like alfalfa, oats and vegetables are replaced progressively by winter crops (wheat and barley). In the segments "B", the area for these crops which consume lots of water is reduced. In the segments "C", the disappearance of alfalfa and the use of water almost exclusively for vegetables (pepper) and arboriculture (olives), the rest of the land is occupied by non- irrigated crops (dry cereals and olives).

5.2.2. Economic and social impacts

Water price leads to a serious reduction in farm income. Water price leads to a serious reduction in farm income, due to the increased cost of production in particular the cost of irrigation water. The farmer responds to price increases by reducing his water consumption through changes in crop plans, keeping less profitable crops as substitutes for more valuable water-demanding crops. This change significantly decreases farmers' incomes. If we analyse the effects on farm income by describing it in terms of the three demand segments, we can observe the same differences in Table 5.

The fall in income is more severe in segment "A", with a reduction ranging from 4 % GDA of Oued Moussa and Oued Zessar) to 13 % (GDA of Amra). This result can be explained by the characteristics of the production system. Indeed, we note that the decline in farm income for the intensive system in the GDA of Amra is more important than the mixed and semi-intensive system respectively characterizing the GDA of Oued Moussa and Oued Zessar. This proves that the agricultural systems (mixed and semi-intensive) are capable of resisting the price increase better than the intensive system. Since the production plan in this system is based on intensive irrigation with areas larger than the area allocated to rainfed crops. The resistance of the agricultural system is described by the inelastic segment "A" which shows that water demand does not respond to price increases until it reaches a level that exceeds 140DT/m3 for mixed farming system to 160DT/m3 for the semi-intensive system (GDA of Oued Zessar) and 180DT/m3 for the intensification system (GDA of Amra). This result shows that the implementation of water pricing policy depends on the characteristics of GDA and orientation of the production system practiced by farmers according to climatic and economic conditions that surround them (type of soil, rainfall, and market).

Table 3 - *Demand segments (DT/m^3).*

	GDA of Oued Moussa	*GDA of Oued Zessar*	*GDA of Amra*
Farming system	Mixed	Semi-intensive	Intensification
Segment A (inelastic)	40-160	40-140	40-180
Segment B (elastic)	180-280	160-220	200-240
Segment C (Inefficient)	> 280	>220	>240

Source: Model results.

Table 4 - *Crop plan by demand segments (DT/m^3).*

GDA	*GDA of Oued Moussa*	*GDA of Oued Zessar*	*GDA of Amra*
Farming	Mixed	Semi-intensive	Intensification
Segment A	Barley, alfalfa, Pepper, olive	Barley, alfalfa, pepper,tomatoes, cucumber, olive ,	Barley, durum wheat, alfalfa, oats, pepper, tomatoes, cucumber, olive rainfed and irrigated
Segment B	Barley and pepper, increase; alfalfa reduced; olive rainfed	Barley and pepper increase; alfalfa disappear; tomatoes, cucumber and olive are stable	Cereals and pepper increase, oats and olives rainfed are stable; alfalfa and olives irrigated reduced
Segment C	Barley and pepper , Increase, alfalfa disappear; olive	Barley and pepper increase; alfalfa disappear; tomatoes and cucumber reduced; olive rainfed and irrigated are stable	Barley and pepper increase; Oats and durum wheat ; alfalfa disappear; olives rainfed increase and irrigated decreases

Source: Model results.

For the social impact, the pricing of water causes a serious reduction in farm labor since farmers respond to price increases by reducing water consumption through change in crop plans. The orientation of agricultural production system to crops that consume less water and are less labor intensive which are based on mechanization, such as cereal crops (durum wheat and barley) and rain-fed tree crops (olive) and some vegetable crops have higher values such as pepper and tomatoes. Table 5 summarizes this reduction in farm labor for each system, analyzing them in terms of the three demand-curve segments.

In segment "A", which is characterized by stability in crop planning and water consumption, there is no decrease in labor inputs for all the agricultural production systems in the three of GDA. While, the reduction of labor inputs was important in the elastic segments "B" for the mixed system because of changes in crop plans to cereal crops with large areas. This reduction is around 18% for this system but it does not exceed 9% for other systems.

In segment 'C', the decline is almost small; it is logical that this segment is inelastic characterizing by stability of water consumption and crop plan. This maximum reduction of labor inputs is about 4 % for the semi-intensive system when the substitution crop is possible between rain-fed and irrigated crops.

The implications of this finding are relevant to policymaking since, if water pricing is the only instrument to reduce water consumption, the existence of the primary inelastic segment does not respond to increased price until it reaches a certain level of water price for each agricultural production system on each GDA. This means that the pricing policy should be a decentralized policy. Determining the price of water depends on the availability of water resources and their cost of extraction at each GDA.The price

Table 5 - *Economic and social impacts by demand segments.*

GDA	*GDA of Oued Moussa*		*GDA of Oued Zessar*		*GDA of Amra*	
Farming System	Mixed		Semi-intensive		Intensification	
Indicators	Farm Income (DT/ha)	Labor (hours/ha)	Farm Income (DT/ha)	Labor (hours/ha)	Farm Income (DT/ha)	Labor (hours/ha)
Segment A	180.73 (4.82%)*	0.00 (0.00%)	191.99 (5.21%)	0.00 (0.00%)	1128.32 (13.71%)	0.00 (0.00%)
Segment B	137.20 (3.79%)	77.28 (17.44%)	122.29 (3.43%)	49.99 (8.37 %)	426.57 (5.47%)	57.97 (7.23%)
Segment C	64.65 (1.82%)	5.62 (1.28%)	178.07 (5.26%)	21.91 (3.81 %)	562.25 (7.67%)	13.99 (1.77%)

* values inside parentheses are percentage reduction from initial point of each segments demand.
Source: Model results.

difference of water between the GDA is logical to maintain profitability and ensure financial autonomy for the administrative and technical operation of GDA for the distribution of water. But the problem is: what is the price of water which does not affect the economic viability of farmers and at the same time allows us to preserve our water resources?

The demand curve for water shows that the optimal price can be found on the elastic segment 'B' and allows the reduction of water consumption by farmers since the segment 'C' is inefficient because no response to price increases. If we analyse the impact of water pricing policy on farm level though the economic and water use indicators. Table 5 shows that the presence of elastic segments B allows us to interpret the political perspective that the water pricing policy is an instrument to control but it is not the only instrument that can be applied for decreasing water consumption. Indeed, the existence of the first segment inelastic 'A' shows that farm income will fall significantly before it affects water consumption. So, the choice of a price in this segment can be interpreted economically as inefficient, since the income will decrease without a reduction in water consumption. From a political perspective, the local decision-maker has no interest to apply such a price in this segment. Even if the segment 'C', if you want to keep the economic profitability of agricultural production system, it is not efficient to apply such a price in this segment.

5.3. Obtaining demand curves for water

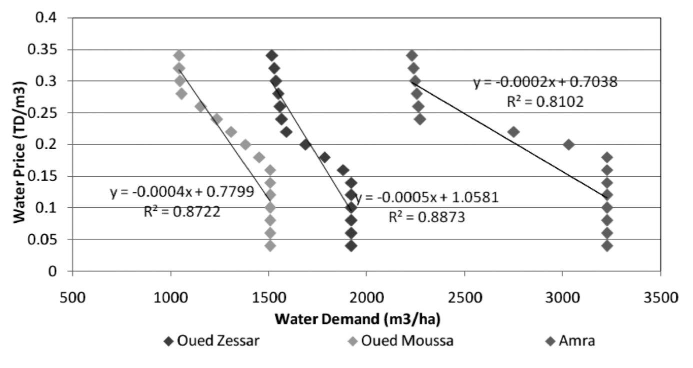
The water price and the total demand of water presented in Figure 1, creating the optimal demand curve (ODC) for each GDA. In this case, it was assumed that the best-fit curve of the water demand is a linear form. But, other equations forms, for example log-linear, may sometimes give the best fitting curve, but application of other types is beyond the scope of the present discussion and will be dealt in later work. In this case the linear form curve is presented by:

$$P_G = a.Q + \beta \qquad (4)$$

Where Q and P_G are respectively water quantities used and the prices; α and β are constants. The estimated coefficients for example of GDA "Oued Moussa" are $\alpha = 0.0004$; $\beta = 0.7799$; and $R^2 = 0.8722$. As expected, different GDA have different demand curves, as in Figure 2. The regression coefficients for demand curves (Eq. (5)) for all the GDA are presented in Table 6. The examination of the ODC for the various GDA shows the following points; (i) generally, the demand curves have a reasonably regular appearance, the exceptions are for the intensification systems, as can be seen the discontinuities (jumps) in the curve for the GDA of "Amra" explained by the presence of large areas with crops are highly water-consuming but low value in terms of profitability; in several cases (as in figure.2), the demand curves becomes vertical at the right-hand side (RHS). This reflects the fact that, in those GDA, at low enough prices all the available land area is being used, the optimal mix of the activities (irrigated and rainfed) remains the same and, therefore, the water demand does not increase as prices drop further . In effect, water demand has upper limit imposed by other constraints (here: irrigable land). (ii) In many cases, like the GDA of "Amra", the ODC becomes vertical at the left-hand side (as in Figure 2). This reflects the fact that at the higher end of the price used, irrigated crops become unprofitable except for very high-value crops like "pepper", usually of limited area, that stay in the optimal basis over the range of prices examined (Table 4).

This analysis of ODC can not only see the shape of the curve but also to spot the inflection point which corresponds to the price level from which water consumption begins to decrease. In order to push farmers to save water we will try, in the next paragraph, to calculate the water demand elasticity at this point "at price noted P_{G*}".

Figure 2 - *Optimal water demand curve.*



5.4. Elasticity of water demand

The water demand elasticity coefficients (WEC) are calculated by:

$$WEC = \frac{\partial Q/Q}{\partial P_{G*}/P_{G*}} \qquad (5)$$

Where Q and P_{G*} are respectively water quantities used and the prices in GDA ($P_{G*}$is the price when the water consumption started to decrease in each GDA). *WEC* coefficients at P_{G*} for the various GDA, calculated using equation (5), are presented in Table 6. It should be noted that these elasticity estimates above reflect the effects of water prices on competition among crops for limited irrigable land.This competition becomes important between irrigated crops forcing the model to choose the most profitable crops and consume less water. But when the numbers are limited, the flexibility of crop pattern is very limited for the case of limited irrigable land, the elasticity becomes high and the discontinuity of the demand curve for water shows large jumps between the snow points as the case of the curve GDA "Amra". In terms of value, the elasticity shows that if policy makers increase the price of water by 10% compared pg, demand will fall by 3% and 3.9% respectively for the GDA "Oued Moussa"and "Amra", but it is 1.7% for the GDA "Oued Zessar". This means that the semi-intensive system is the most stable for

Table 6 - *Regression coefficients of optimum water demand curves and water demand elasticity.*

GDA	*Coefficient α*	*Coefficient β*	*R^2*	*P_G: Price*	*Elasticity (at P)*
Oued Moussa	0.0007	0.7799	0.8722	0.180	0.300
Oued Zessar	0.0005	1.0581	0.8873	0.160	0.178
Amra	0.0002	0.7038	0.8102	0.200	0.397

external shocks while keeping the socio-economic profitability with a slight decrease of income and labor (Table 5). This system also restricts the immigration of farm labor to their economic sectors and prevents the failure of regional agricultural market.

6. Conclusion

This paper analyzed the impact of water pricing policy on the demand function of water in public irrigation system "GDA" in Tunisia. The analysis of the response function of the demand for irrigation water has shown the sensitivity degree of each production system due to the change in water prices. The elasticity of prices showed that the water demand curve is divided into three segments which explains the behavior of farmers towards pricing water through flexible plan crops and competition between irrigated crops for limited irrigable land. The analysis of these segments shows that the price incentive for farmers to adopt water saving technology may be on segment B. Therefore, the determination of water prices for irrigation should not be a financial action of the GDA, but it must consider more than the techniques characteristics of the GDA and the availability of water, the importance of the information about the agricultural activities practiced by the farmers in each GDA.

The price is an instrument to control and to induce the farmers to adopt water-saving technologies without affecting their selection of crops. From a methodological point of view, it would be interesting to complement short-term analyses of response with long-term dynamic adaptation models, including analyses of technical change (adoption of water-saving techniques, etc.). Furthermore, in order to construct more realistic models, multicriteria techniques and regional model should be adopted in further research on irrigated agriculture.

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