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Marginal Water Productivity of Irrigated Durum Wheat in Semi-Arid Tunisia

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Abstract

Recent studies on agricultural water management in Tunisia report low water productivity for some of the currently widely cultivated crops such as durum wheat. The objective of this study is to estimate water productivity and marginal value of irrigation of durum wheat in central Tunisia. We develop a production function, in which the durum wheat irrigation revenue of farmers per hectare is expressed in terms of the used water volume in addition to other production factors. The function was estimated for a sample of durum wheat farms from Central Tunisia. Results show that 31.7% of the farmers were applying water volumes above the economic optimal volume (more than 2700 m^3/ha). Moreover, 50% of the farmers were found to be applying less irrigation water than this optimal volume. Applying water above the optimal volume means that the benefit farmers obtain from each supplementary unit of irrigation water is lower than the market price of irrigation water currently applied in the region (0.110 TND/m^3). Then, water is wasted. However, using less water than the optimal volume means that farmers can make further supplementary irrigations and obtain more benefit from it (extra-yield). The study also shows that most of the farmers in the study area do not apply good practices with respect to irrigation scheduling and irrigation doses. Improving irrigation performance will largely preserve water resources and enhance food security in Tunisia.

Keywords: irrigation, production function, marginal water value, durum wheat, Tunisia

1. Introduction

The portion of fresh water currently available for agriculture is globally decreasing (Cai & Rosegrant, 2003) while at the same time the agricultural production from irrigated areas must be increased in order to satisfy the growing food demand, especially in developing countries. The search for sustainable methods to increase crop water productivity becomes more and more urgent especially in arid and semi-arid regions (Debaeke & Aboudrare, 2004). This productivity issue is particularly important in irrigated areas where deficit irrigation is used as alternative production strategy.

Optimal techniques and management practices of irrigation water at farm and local level are determinant factors for its productivity (Oweis & Hachum, 2005). Wichelns (2002) states that economic efficiency of irrigation water, which is defined as maximizing social net benefits from water resources, often requires improved water management even when basin-wide measures of irrigation efficiency are relatively high. Optimal irrigation management includes the choice of crops, varieties, techniques, and institutions. This may increase the productivity of each unit of water applied for irrigating the cultivated crops (Pereira et al., 2002).

In Tunisia, during the last 30 years, irrigated area has increased from 250,000 ha in 1990 to 450,470 ha in 2010 (MA, 2011). Although the irrigated areas represent only 8% of the total agricultural surface, irrigation contributes with 35% to the total agricultural production and with 20% to agricultural exports. The growth of the agricultural production in the recent years is mainly due to the expansion of irrigated areas (Al-Atiri, 2009). However, the increase of irrigated area has clear impact on the country's water resources (Frija et al., 2011). The issues of improving agricultural water management and increasing water savings are highly debated and undertaken by policy makers and researchers. Recent studies about irrigation economics in Tunisia focus on the assessment of the current efficiency of the resource use (Dhehibi et al., 2007; Albouchi et al., 2007; Frija et al., 2009; Chemak et al., 2010; Chebil et al., 2012), on the impact of some agricultural policies (such as water pricing), on water allocation and use (Bachta & Talbi, 2005; Zekri, 2005; Frija et al., 2011), and on the effectiveness of local collective irrigation water management (Frija et al., 2010, 2008; Ben Salem et al., 2005). While most of these researches call to encourage farmers to adopt higher valued crops as a strategy to face water scarcity in the country, little research has been done to evaluate irrigation water productivity and to analyze the marginal benefit of water use for different crops and seasons.

In this study, we are interested to investigate the productivity of water applied for the irrigation of durum wheat in Central Tunisia. Durum wheat holds the most important place among cereals in Tunisia in terms of production and cultivated area. It occupies about 50% of all cereals area (estimated to be around 1 370 000 Ha in 2012, of which 25 % is located in the semi-arid central part of the country) and represents, in average, almost 55% of the total cereals production (MA, 2010). Total cereal production, including durum wheat, tender wheat, barley and triticale, is estimated around 1.6 Million tons in 2012. Durum wheat production in the same year was about 0.67 Million tons. Around 17.7% of the total irrigated area is cultivated with cereal crops. The potential increase of water value used in the irrigation of this crop is crucial. It may have important implications on food security and resources preservation.

Wheat is produced in most areas in Tunisia, but the most important areas are the North (sub-humid) and the Centre (semi-arid). Rain is more abundant in the North than the Center, which means that supplemental irrigation is needed especially in the Center. Moreover, irrigation water reservoirs are more important in the North. The most important governorates producing cereals in Tunisia can be classified based on the cultivated area as follows, El Kef (North), Seliana (North), Beja (North), and Kairouan (Center), with an area of 214,000 ha, 158,000 ha, 145,000 ha, and 144,000 ha respectively (MA, 2010). Kairouan is considered as the most important governorate for cereal production in the Central part of Tunisia, and will be considered for this case study.

The objective of this paper is then twofold; first, to calculate the marginal value of water used for the irrigation of durum wheat in the region of Chebika (Governorate of Kairouan). This will be done through the estimation of a "Cob Douglas" production function using field data from 170 farmers located in the region of Chebika. Marginal value of irrigation water can be then derived from the estimates of the production function. According to the neoclassical economic theory, the comparison of this marginal value to the market price of irrigation water may provide insights on the effectiveness of water use at the farm level. The second objective is to evaluate the implication of this water use effectiveness both on private farmers' income and food security in Tunisia.

The paper is divided into 6 major sections. The next section describes the cereal production sector in Tunisia and stresses the importance of the efficient use of irrigation water in Tunisia. The third section presents the "Cobb Douglas" production function used for the marginal water value estimation; as well as the characteristics of the study area. The fourth section presents results, and the fifth one discusses them. The last section concludes.

2. Methodology

Marginal water value for the durum wheat crop will be estimated in this study in order to see if farmers are producing at the economic optimum when the marginal value of irrigation water is equal to market price of this resource (Frija et al., 2011). Moreover, marginal value of irrigation water is an indicator of the extra income generated by any additional unit of irrigation water applied to the crop. In this methodological section, water productivity, and marginal water productivity concepts will be defined and the estimation method will be explained.

2.1 Economic Water Productivity

The concept of water productivity may carry different meanings when it is looked from different perspectives (agronomic, economic, and domestic). Moreover, it may differ between as well as within groups of water users (Wesseling & Feddes, 2006; Dugan et al., 2006; Playán & Mateos, 2006). Water productivity can be defined with respect to different water-using production sectors (e.g. crop production, fishery, forestry, domestic and industrial uses) (Igbadun et al., 2007) as the amount of output produced per unit of water involved in the production, or the value added by water in a given circumstances (Ali & Talukder, 2008).

In crop production systems, water productivity is generally used to define the relationship between crop produced and the amount of water involved in crop production, expressed as crop production per volume of water. Molden et al. (2010) distinguish between physical water productivity defined as the ratio of agricultural output to the amount of water consumed, and economic water productivity defined as the value derived per unit of water used for producing a given agricultural output. The crop production used to calculate water productivity may be expressed in terms of total yield (kg) of seed (grain) or, when dealing with different crops (e.g. water productivity at the farm level, all crops included), yield may be transformed into a monetary value (Ali & Talukder, 2008; Hellegers et al., 2009). The economic formulation of water productivity used in this study can be written as follows (based on Hellegers et al., 2009; Ali & Talukder, 2008):

$$WP = \frac{PV}{W} \tag{1}$$

Where

WP is water productivity (expressed in TND/m^3) and *W* is the volume of applied water per hectare of durum wheat (expressed in m^3). *PV* is the production value defined as in Equation (2) (expressed in TND/ha):

$$PV = P_y Y \tag{2}$$

Where

Y: Gross output (Kg per ha);

P_y: Unit price of durum wheat (in TND/Ton).

WP calculated using Equation (1) gives useful information about average income generated by one cubic meter (m^3) of water used to produce durum wheat. However, for a policy maker who may need to act to change the water use pattern, this information is not sufficient. In fact, policy makers need to have information about the marginal value of water or productivity of a one-unit-increase or decrease of water use on the different crops income, this variable is called the marginal productivity of irrigation water. Ali et al. (2007) define the marginal productivity of irrigation water as the addition to the gross output caused by the use of one extra unit of water while other inputs remain constant. According to the economic theory, as long as the marginal value of water applied for the irrigation of a given crop, is higher than the market price of water (unitary water cost for surface water or pumping cost per cubic meter for groundwater), it will be still profitable to apply supplement doses of irrigation to the crop.

Marginal productivity (MP) of irrigation water can be calculated as:

$$MP = \frac{\Delta Y}{\Delta W} \tag{3}$$

Where

ΔY is the variation of the gross output due to the variation of irrigation water *(ΔW) applied*.

Based on this latter definition, "marginal profitability of irrigation water" (MWP) in this paper will be calculated as (Hellegers et al., 2009):

$$MWP = \frac{\Delta(PV)}{\Delta W} \tag{4}$$

ΔPV is the variation (change) of the production value per hectare after addition of one unit of irrigation water. Marginal water productivity will be derived from the estimation of the "Cobb-Douglas" production function explained in the next section.

2.2 Production Function

In agricultural water management, production functions are mostly used to predict the yield of crops given some input parameters (Igbadun et al., 2007). For agronomists the crop-water production function expresses the relationship between yield (Y) and the applied water (W). In this paper, considering the economic and policy-advising perspective, the water production function is used to model revenue response to various levels of irrigation (Oweis & Hachum, 2009). Our production function is expected to relate the income generated by durum wheat in the region of Chebika to the water volumes used by this crop in addition to other production factors. The general production function used can be implicitly presented in the following form:

$$PV = f(W, X_j) \tag{5}$$

Where

(PV) is the output value per hectare (TND/ha); (W) is the volume of applied water (m^3) per hectare and (X_j) are the quantities of other *(j)* productions factors (expressed in m^3 for water and TND for other inputs: labor and fertilizers).

The most widely used functional forms for production functions in the analysis of agricultural production are the "Cobb-Douglas" and Translog function (Sahibzada, 2002). The second functional form can be approximated by a second order Taylor series and requires estimating a large number of parameters. For this reason, large datasets are usually needed when estimating a Translog production function, otherwise multi-collinearity can be often a major problem. We therefore rely on the Cobb-Douglas production function. Advantages of the "Cobb-Douglas" function are the parsimony in parameters, the ease of interpretation, and the computational simplicity (Sahibzada, 2002).

The general logarithmic form of the production function presented in (5), thus becomes:

$$Ln(PV_i) = a + b \cdot Ln(w_i) + \sum_{j=1}^{J} c_j \cdot Ln(X_{i,j}) + u_i, \quad \text{i (1, …, n) farmers} \tag{6}$$

Where *Ln* is the Natural logarithm, *u* is the error term, *(a)* is a constant and *(b)*, *(c_j)* are the estimates of the production function. *(b)* can also be considered as the output elasticity of the water variable. Output elasticity measures the responsiveness of output to a change in the volume of water applied to the crop. The marginal value of irrigation water applied to durum wheat is calculated from the coefficient *(b)* in the Equation (6) above. In fact, since *(b)* is expressing the elasticity of water use, it can be written as follows:

$$b = \frac{\Delta PV}{\Delta W}\frac{W}{PV} \tag{7}$$

For a given water volume, if we multiply *b* by $\frac{PV}{W}$, we may obtain $\frac{\Delta PV}{\Delta W}$ which can also be written as :

$$\frac{PV_2 - PV_1}{W_2 - W_1} \tag{8}$$

This latter term is interpreted as the variation of the output value (PV) due to a given change of the water input (W). The result will be a value expressed in TND/m^3, which is corresponding to the marginal value of irrigation water at a given level of water use.

Figure 1 illustrates the decreasing marginal productivity derived from the production function. The economic optimum volume of water applied should be, according to the neoclassical economic theory, equal to the market price of water. In Figure 1, the economic optimum corresponds to the volume V^*. A farmer applying a volume V_2 of water may increase his production from PV_2 to PV^* if he makes supplementary irrigation of (V^* - V_2). This means that the farmer will have extra income from supplementary irrigation as far as the value of this extra income per unit of water (MWP_2) is higher than the price of acquisition of this production factor (MWP^*). Using the same logic, farmers who are applying V_1 volume of water (higher than V^*) are generating less benefit (MWP_2) from their supplementary irrigations than the price they are paying for the acquisition of water.

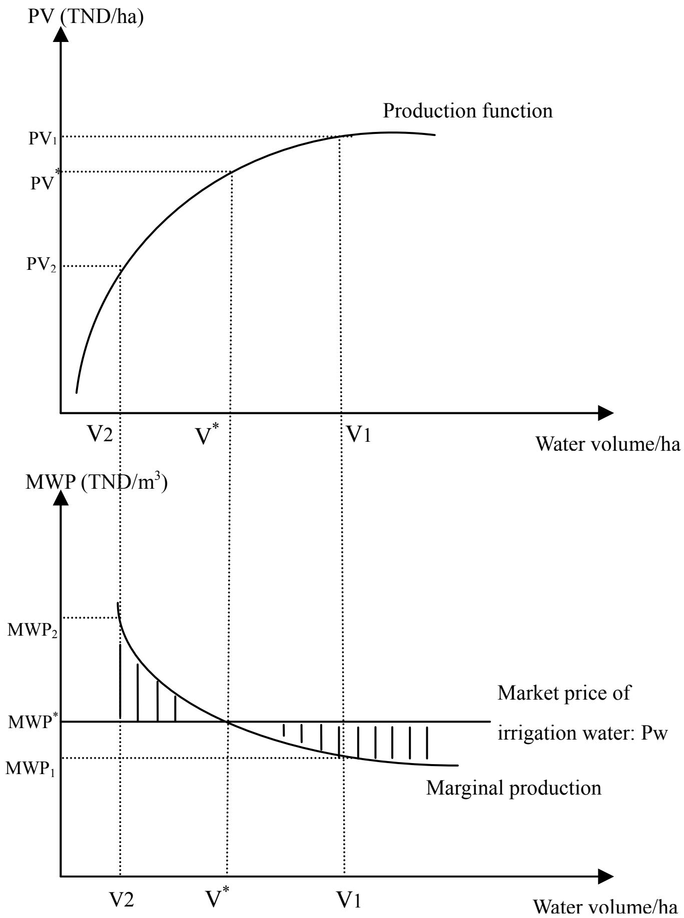


Figure 1. Derivation of marginal water value from the water production function (PV: production value (in TND/ha); MWP: marginal water productivity (TND/m^3); V: water volume applied)

Consider *MWP = f(Water)* the Equation of the marginal production curve (Figure 1), which is obtained from deriving the production function on the water variable. The farmers' loss, due to application of V_1 cubic meter of irrigation (higher than the economic optimum V^*), can be calculated by the following formula:

$$S = P_w(V_1 - V^*) - \int_{V*}^{V1} f(w)dw \quad (9)$$

Where

S is the hatched area comprised between V_1 and V^*; and P_w is the market price of water in the region. The same concept can also be used to calculate farmers' loss due to application of any water volume lower than the economic optimum.

2.3 Data and Study Area

The study area is the Chebika region, located in Central Tunisia in the governorate of Kairouan. Chebika has an annual average rainfall of about 290 mm. This average is varying between 250 and 400 mm. The main crops cultivated in the area are: wheat, vegetables (especially Tomato and Chilli pepper), fodder and olives. The number of farmers in the irrigated area of Chebika is around 1000. Total overall cereals area is 17500 ha (in 2009). The irrigated cereal area is 4500 ha and the average regional yield of the irrigated durum wheat is around 3.9 tons/ha (CRDA, 2010).

The data employed in this study consists of the information about the production structure of 150 random wheat farms located in the irrigated area of Chebika. The used data corresponds to a farm level data where each of our 150 observations corresponds to a different farm. Inputs and yields were aggregated in some cases from plots to farm level. In order to ensure homogeneity in land and weather conditions, farms in the sample have been chosen from the same region of Chebika, and are located in a 20 Km diameter. Chebika is facing growing problems of water scarcity. Some of the data used in the study was collected in 2011. This data was completed and updated in 2013 with the collaboration of the extension service in the region, by face-to-face interviews with cereal-growing farmers.

Farmers in the study area are irrigating from both groundwater and surface water source. One among the largest dams of Tunisia is located nearby Chebika. In addition, a wide and accessible water table, covering the whole surface of the governorate of Kairouan (in addition to extra surfaces from other neighboring regions) is also available for farmers' exploitation. The irrigation systems which can be found in the study area are diverse, ranging from gravity to drip irrigation. Drip irrigation is however widely spread and some farmers are even irrigating cereals using this technology.

3. Results and Discussion

3.1 Descriptive Results: Cropping System, Water Use Patterns, and Water Productivity

Average land distribution in the sample shows that the average farm size is 16.19 ha with 88% of this area cultivated under irrigation and the rest under rainfed conditions. The farming structure is characterised by the predominance of small-size farms and land fragmentation. Farms with a cropped area lower than 20 ha represent 80% of the total number of farms in Chebika. The size of 38% of the surveyed farms is lower than 10 hectares.

Regarding land use, most cultivated crops in the target area are vegetables (especially tomatoes and Chilli pepper) followed by durum wheat. They occupy, respectively, 30.24% and 27.46%, in average, of the total area of the sample farms.

The first irrigation of durum wheat in the public irrigated areas in Tunisia is free of charge. Moreover, farmers of our sample have different educational background, while some of them are highly educated and trained on irrigation scheduling, others are much less educated and believe that in semi-arid condition, as mush water you give will be beneficial. Another reason of this strong variability is the different level of water constraint in the investigated farms. In fact, while some farmers are specialized in cereal production, and then allow all available water resources to these crops, others have more diversified cropping systems and are cultivating different vegetable crops in addition to cereals. Thus, the latter ones will be faced to choices on water allocation among many cultivated crops; which can be implicitly interpreted as higher water shortage for the cereal crop.

Table 1 presents some descriptive statistics of main inputs and outputs used in durum wheat production in the study area. As discussed in the previous paragraph, the volume of irrigation water applied per hectare varies between farmers. It ranges from 480 m^3/ha to 6172 m^3/ha (Table 1). The sample average is 2720 m^3/ha (standard deviations, variation coefficients, minimum, and maximum values are indicated in Table 1), which is a bit lower than the average estimated annual water requirement of durum wheat in the region (around 3000 m^3) (MA, 2000; Rezgui, 2005). Volumes of water applied by each farmer were recorded by the Water Use Association (WUA) to which the farmer belongs. In fact, volumetric tariffs are applied in the study area, and each volumetric water meters are installed to each farmer in order to record its water consumption. Other inputs considered are fertilizers and labor, both expressed in monetary terms. The labor variable includes both family as well as hired labor. The number of working days, as well as the daily wage were surveyed from farmers and used to elaborate this variable. The average production value per ha in our sample is equal to 2226.26 TND, corresponding to an average yield of 3.9 tons/ha. Expenditures for other inputs like mechanization and seeds are very homogenous among farmers. In average, farmers in the study region apply around 200 kg of seeds per ha.

Table 1. Descriptive statistics of production factors and production value per ha of durum wheat in the study area

Variables	Unit	Average	SD	VC (variation coefficient%)	Min	Max
Production value per ha	TND/ha	2226.2	636.4	28	1016.0	4370.0
Water	m^3/ha	2720	1110.8	40	480.00	6172.00
Fertilizers	TND/ha	142.2	60.02	42	33.00	338.00
Labor	TND/ha	66.46	22.3	33	31.50	178.75

3.2 Marginal Water Values

The parameters of the "Cob Douglas" production function were estimated using Eviews (econometric views) software, version 4.1. Results of the coefficients and related tests are shown in Table 2.

Table 2. Coefficients of the production function and *t*-test

	Coefficients	*Standard Error*	*t*	*P-value*
(Constant)	4.305	0.328	13.092*	0.000
Ln (water)	0.151	0.036	4.189*	0.000
Ln (fertilizers)	0.170	0.045	3.729*	0.000
Ln (labor)	0.324	0.070	4.596*	0.000
R Square	*0.430*			
Observations	*170*			

** Significant at 5% level.*

Using the estimated parameters and the Equations (7) and (8), we calculated the marginal value of water applied to the wheat production in Chebika region. The marginal value of irrigation water varies according to the quantity of water applied, which is shown in Figure 2. The curve of marginal water value in Figure 2 corresponds to the theoretical expectations, where the marginal value of water is negatively correlated to the volume of water applied. According to the economic theory, farmers will use water until the marginal value of water will be equal to the market price of this factor. Since water price in the study area is 0.110 TND/m^3, this value corresponds to 2700 m^3/ha of water.

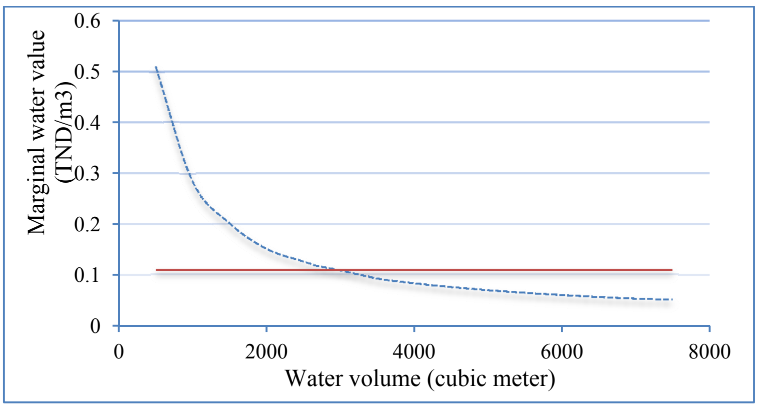
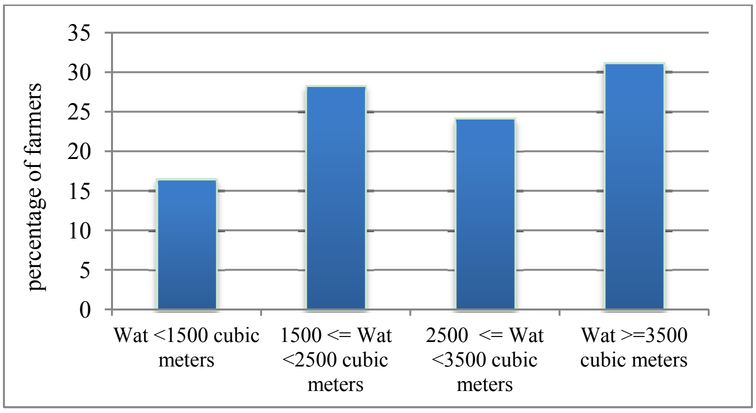


Figure 2. Marginal value of water applied to the durum wheat crop in the study area (Hachured curve indicates the marginal water value for different applied volumes of water; continued line refers to the water market price, which is around 0.110 TND/m^3)

If we consider the range of water use between 2500 m^3 and 3500 m^3 as relatively economically rational, then we can observe from Figure 3 that most of farmers in the sample are either applying less than the economically optimal volume (44.6%) or more than this optimum (31.1%). Results derived from this descriptive analysis of the water use pattern in the study region show that most of the farmers are not using irrigation water effectively.



(*Wat: volume of water*)

Figure 3. Farmers distribution according to their total supplement irrigation water applied during durum wheat cycle

Some wrong cropping practices related to the irrigation of durum wheat in the study region have then to be stressed. In fact, the average supplemental irrigation of durum wheat reaches 2700 m^3/ha in average; which is a bit lower than needed (after considering the average annual rainfall). Also, 44.6% of the surveyed farmers apply less than 2500 m^3/ha (Figure 3). Moreover, we find out that 25% of the farmers irrigate durum wheat less than three times applying on average 780 m^3 per irrigation. Irrigation scheduling in the study area was also random and only few farmers are aware about the importance of scheduling irrigation and fertilization supplements (Figure 1).

According to the economic theory expectations, each unit of water applied beyond 2700 m^3/ha, which is the economic optimum of producers, will generate less return than its price indicating that farmers incur a net loss from this last unit of irrigation. This is also true in our case study where we can see that the average per ha production value of the farmers applying more than 3500 m^3/ha is lower than the average per ha production value of farmers irrigating with less than 3500 m^3/ha (Table 2 and Figure 3).

3.3 Analysis of Private and Social Losses Due to Inefficient Irrigation Practices

Farmers' private losses, for different volumes of irrigation lower and higher than the economic optimum, were calculated based on Equation 9. It is clear from the results (Figure 4 and Table 3) that private losses due to underutilization of irrigation water are more important than the private losses due to the overuse of water. For example, farmers who are applying only 500 m^3 of water may win around 220 TND/ha of net benefit, which can be generated if they shift their irrigation to the economic optimum. This extra benefit is due to an increase of durum wheat production. Total yield increase for these farmers can be calculated by adding the cost of extra water applied per ha to the extra-net-income (220 TND/ha) and dividing by the price of durum wheat (570 TND/ton). For example, in the case of 500 m^3 irrigation, total yield may improve with [(220 + (2700 - 500) * 0.11)] / 570, which corresponds to 0.81 tons/ha. Such yield improvement, generated only from performing the irrigation of durum wheat, will surely have important implications in terms of food security and trade balance in Tunisia.

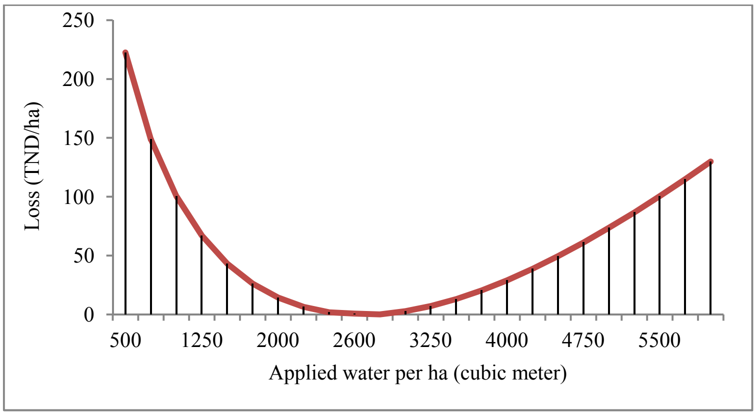


Figure 4. Private loss per hectare due to the irrigation beyond and below the economic optimum volume (in TND/ha)

Table 3 shows the potential to enhance food security and natural resources preservation if irrigation of durum wheat will be better performed. It shows that farmers applying 1000 m^3, 1500 m^3 and 2000 m^3 may increase their yield per hectare with successively 0.5 tons/ha, 0.31 tons/ha, and 0.16 tons/ha. Moreover, overuse of water also causes a social loss which calculated in the Table 3 as the difference between the total cost of non optimal irrigations minus the value of the obtained extra-production. This cost is then expressed in cubic meters of water.

Table 3. Potential improvements in yields and water resources preservation

Water volume (m^3/ha)	Marginal water value (TND/m^3)	Water price (TND/m^3)	Loss due to under-application of irrigation water		Loss due to the overuse of water	
			Private loss in TND/ha	'Social' loss in tons/ha	Private loss in TND/ha	'Social' loss in m^3/ha
500	0.489	0.11	222.59	0.82	-	-
1000	0.291	0.11	100.49	0.50	-	-
1500	0.206	0.11	43.15	0.31	-	-
2000	0.155	0.11	14.29	0.16	-	-
2500	0.129	0.11	1.79	0.04	-	-
2600	0.124	0.11	0.70	0.02	-	-
2700	0.120	0.11	0.00	0.00	0.00	0.00
3000	0.111	0.11	-	-	2,7	275,45
3500	0.096	0.11	-	-	13,02	681,64
4000	0.086	0.11	-	-	29,04	1036,00
4500	0.078	0.11	-	-	49,5	1350,00
5000	0.072	0.11	-	-	73,53	1631,55
5500	0.066	0.11	-	-	100,5	1886,36
6000	0.062	0.11	-	-	129,92	2118,91

4. Discussion and Perspectives

Variability of water use among farmers for different cropping systems in Tunisia was also identified in different other studies (Dhehibi et al., 2007; Albouchi et al., 2007; Frija et al., 2009; Naceur et al., 2010; Chemak, 2010; Chebil et al., 2012). All of the previous studies point out large differences in applied water volumes among farmers of same regional and agro climatic areas. These differences can be due to technical and/or socioeconomic factors. Frija et al. (2009) find out that farmers training about irrigation issues, in addition to their investments in water saving technologies, are explaining much of the variability in water use among farmers growing horticultural crops under green houses in Tunisia. The same variables were found to be relevant by Naceur et al. (2010), and Dhehibi et al. (2007). In addition, the latter authors found that farmers' education level and the farm size are also explaining the variability of water doses among farmers of same regions and cultivating the same crops. Access to credits was also found to be explicative of this variability (Dhehibi et al., 2007; Albouchi et al., 2007; Chebil et al., 2012).

Efficient water management in irrigated cereal production systems in Tunisia was found as having important implication in terms of farmers income, food security (yield enhancement), and natural resources preservation (Table 3 and Figure 4). In Tunisia, as it is in most semi-arid regions of the world, the water preservation and food security nexus is becoming more and more important. Urgent water policy actions need to be taken in order to deal with the climate change, water and energy scarcity, in addition to the micro-credits crisis. According to Hanjraa and Qureshi (2010) investments are needed today for enhancing future food security; this requires early actions on several fronts, including tackling climate change, preserving land and conserving water, modernizing irrigation infrastructure, shoring up domestic food supplies, etc. More specifically, the yield gap of the cereal production systems of central semi-arid Tunisia needs to be seriously studied, and the effect of wrong irrigation practices and scheduling in reducing the potential cereal yield will have to be identified.

Irrigation practices and scheduling were also identified by Chebil et al. (2012) as significant variables affecting the performance and the productivity of water use in semi-arid Tunisia. In fact, the latter authors found that the source of irrigation, the adherence to WUA, and the size of irrigated areas are highly affecting water use efficiency (and implicitly the waste of water) in the cereal production systems of Kairouan. In the region of Nadhoun (neighboring region to Kairouan) Chebil et al. (2010) also found that the contact with extension services is significantly and positively affecting farmers' water use efficiency at the farm level. Thus, clear targeted and efficient water-related policies should be taken in order to further enhance cereal production and water productivity in these cropping systems. Particularly, the role of extension services and farmers' technical training about water scheduling issues should be deeply settled in any future policies.

5. Conclusions

The objective of this paper is to evaluate the valorization of irrigation water applied for the irrigation of durum wheat in Central Tunisia. Water use patterns as well as the water productivity and marginal water profitability were calculated and estimated for this purpose.

Results show that cereal farmers in central Tunisia are not applying the appropriate water doses nor the irrigation scheduling adapted to their local conditions. In fact, we found that most of farmers are applying either lower or higher volumes than the economic optimum dose. Calculations also show that this may have great implications in terms of food security and water resources preservation. Improvements of irrigation performances in cereal production in Tunisia are absolutely necessary because of the significant challenges in terms of water scarcity and economic vulnerability. Further human, financial, and technical resources have to be mobilized in order to enhance the performances of the specialized regional and local extension services. These services in Tunisia are exclusively provided by public administrations. The creation and encouragement of private extension sector could be then proposed as an opportunity of agricultural productivity enhancement.

Further enhancement can be considered to improve the current version of the paper and to deepen the analysis. It will be in fact highly interesting to add further farming inputs to the production function. Even though this is not really a limitation of the current analysis (since the water coefficient used for our interpretation was highly significant), it will be indeed interesting to see whether the water coefficient change when we add some other variables or not. Moreover, testing further functional forms of the production function (such as translog function) will consolidate the obtained estimates of our production function. Furthermore, relevant surveys can be done in order to further understand the origin of the very remarkable variability of irrigation doses among farmers.

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