Emirates Journal of Food and Agriculture. 2022. 34(9): 792-799
doi: 10.9755/ejfa.2022.v34.i9.2944
http://www.ejfa.me/

RESEARCH ARTICLE

Irrigation water demand management to address water scarcity

Hassen Abdelhafidh, Ines Gharbi, Ahlem Maaroufi

Agricultural Economics Department – LR-SPADD (LR03AGR02), Higher School of Agriculture of Mograne, Zaghouan1121- University of Carthage, Tunisia

ABSTRACT

Improving irrigation water productivity is one of the most important ways to deal with water scarcity. Water pricing is considered a crucial tool for water demand management. This research aims atestimating the price elasticity of irrigation water demand in public and private areas of Nadhour using an Ordinary Least Squares regression (OLS). The paper assesses the economic performance of farming system and compares the value of marginal productivity (VMP) of irrigation water to the prices of water. A structured questionnaire and field visits were used to collect data from 140 farmers. Results show that irrigation water demand is less responsive to water price variation. Estimated elasticities are-0.69 and -0.44 respectively in the public and private schemes. The total irrigated area and farmers' status are the most significant determinants of water demand. Results showed that water productivity in private farming systems is higher than recorded in public farming systemsand the VMP of irrigation water exceeds the prices paid for water.

Keywords: Price elasticity; Tunisia; Value of marginal productivity of water; Water pricing; Water scarcity

INTRODUCTION

The adaption of irrigation schemes to water shortages in the dry regions of the world continues to use cost-effective measures to ensure food security and enhance farm incomes. These concerns call into question the sustainability of growth and the well-being of small-scale farmers who bear much of the cost of water shortages that irrigated agriculture might face. The Tunisian agriculture remains the most consumer of fresh water with more than 80% of its resources. For both renewable and non-renewable resources, the state has mobilized nearly 95% of the resources, including groundwater resources. These latter contribute greatly to meet the needs of different economics sectors. This mobilization has taken part in the development of irrigation, the diversification of agricultural production and the supply of drinking water to urban and rural areas. Since the mobilization policy has reached its limit, it is very important that the use of water is optimized. Indeed, the lack of control of water demand in Tunisia has led to the waste of this crucial resource. As a result, there is inadequate water for irrigation in Tunisia, and the quality of available water is decreasing. Various latest studies showed surprising outcomes of the use of efficacious irrigation practices. An efficient use water for irrigation may decrease irrigated areas, increase the cultivation of water-intensive crops when the effective price of water is lower (Sun et al, 2017), and results in the over withdrawal of groundwater resources (Abdelhafidh and Bachta, 2016; Huang et al, 2017). Water demand analysis is an essential part of water resources planning and management as it helps to identify where future supply development will bring the greatest benefit. The economics of water includes expertise its shortage and value, in addition to human needs, and making sure that the costs and advantages of alternatives are clear and the effects of opportunity pricing schemes are determined. However, information on irrigation water demand at small-scale schemes is limited and in general little attention is paid to the determinants of these values (Mahdhi et al, 2014; Abdelhafidh and Bachta, 2017). Rational water management issues require infallible estimates of water demand, particularly for agricultural sector, this fact is important to design fair, informed, and rational pricing systems, providing incentives to irrigators to use water rationally and efficiently and permittingcosts recover. However, data on irrigation water demand in

Corresponding author:
Hassen Abdelhafidh, Agricultural Economics Department – LR-SPADD (LR03AGR02), Higher School of Agriculture of Mograne, Zaghouan1121- University of Carthage, Tunisia. **E-mail:** abdelhafidhhassen@yahoo.fr

Received: 11 April 2022; **Accepted:** 21 August 2022

small-scale perimeters is scarce and, in general, little interest is given to the factors affecting those values (Mahdhi et al, 2014; Abdelhafidh and Bachta, 2017; Abdelhafidh et al., 2021). Rational decision-making on water management problemscalls for reliable estimates of water demand. Mainly for the agricultural sector, this information is essential for designing equitable, knowledgeable and rational pricing systems, incentivizing irrigators to apply water rationally and efficiently and recovering costs. In Tunisia, irrigated agriculture is considered an important aspect in rural development, creating employment opportunities, producing income and improving food security. Extensive irrigated areas and drought cause growing concern on groundwater resources. Considerable attempt has long gone into introducing policy tools to attain sustainable irrigation water management (Jeder et al., 2014; Abdelhafidh et al., 2022). Thus, the new strategy put in place in the 90s turned towards the management and regulation of water demand, while continuing the effort to mobilize water (Bachta et al., 2004). The main objective of this strategy is to conserve water resources and encourage demand management in the irrigation sector. Knowledge of water demand can contribute to improving the efficiency via better water management at the farm level. Indeed, water pricing is taken into consideration as one of the most crucial economic tools in the water demand management strategyto mitigate both the quantity and quality dimensions of water scarcity. However, it has remained largely subsidized for a long time and has not reflected the real production costs of resource (Chebil et al., 2010, Abdelhafidh and Bachta, 2016; Jeder et al, 2019). Considering the irrigation water needs covered by groundwater in Tunisia, hypothesizes that using agricultural water is sensitive to irrigation water price (water price paid by farmers who are members of a water user association or water pumping cost paid by private farmers). Pricing incentives concerning higher irrigation water costs can reduce producers water consumption. This study aims at estimating the agricultural water demand in both private and public schemes in a first step. In a second step at examining expected effect of water costs on water request and finally atcalculating the marginal value of irrigation water usein the region of Nadhour, North of Tunisia.

IRRIGATION WATER DEMAND AND PRICE-RESPONSIVENESS

Water control alternativesareclassified as both supply management or demand management. Historically, watercivilengineers centered on large-scale infrastructure projects to increase water supply, while economists and environmentalists recommended water use efficiency enhancements policies related to demand management (Katz, 2016). Each approach has its relative merits.When supply is limited, water demand management becomes the only alternative to water management. Demand management alternatives are frequently much less costly, more economically efficient, and with minimal terrible environmental effects than increased water supply (Dolatyar and Gray, 2000; Butler andMemon, 2006). Irrigation water management is of great interest in the implementation literature for many reasons. First, rainfed agriculture is known for the low productivity, indeed, it appears incapable to meet population food requirements. Second, irrigation is commonly the biggest consumer of mobilized water. Third, water productivity in agriculture is the lowest compared to competing sectors such as tourism and industry. Finally, agriculture benefits from significant water subsidies relative to other users. Efficient pricing of irrigation water is generally recommended to meet growing demand (Berbel and Gómez-Limón, 2000; Frija et al., 2011). Pricing policies are reviewed in several empirical studies, particularly in arid countries (Varela Ortega et al., 1998; Berbel and Gómez-Limón, 2000;Frija et al 2011; Abdelhafidh and Bachta, 2016; Abdelhafidh and Bachta, 2017; Sun et al 2017; Garrone et al., 2019; Grafton et al, 2020). These research display that water pricing would not usually stimulate the favored adjustment in water use because of the low elasticity of demand for irrigation water. A limited effect is expected mainly if the share of water cost is low compared to other production factors (Moore et al., 1994; Berbel and Gómez-Limón, 2000; Salman and Al-Karablieh, 2004). This implies that increasing the price of water will not significantly reduce demand and will not be efficient because water users are not much responsive to water pricing (Berbel and Gómez-Limón,2000; Salman and Al-Karablieh,2004; Huang et al., 2010; AbdelhafidhandBachta, 2017). Moore, Gollehon and Carey (1994) proposed a multi-crop production model to study the marginal effects of water price on each intra-seasonal water use (the intensive margin) and crop choice in an irrigated area (the extensive margin) in four countries. regions of the United States; Northwest, Central Plains, Southwest, and Southern Plains. Their findings suggest that the response to the water price occurs primarily at the extensive margin, with irrigated areas moving to crops with lower water requirements as the water price increases. On the other side, Scheierling et al. (2006) show that the water demand is elastic and the price of water is a strong determinant of water demand and is an important incentive for farmers to adjust their irrigation water requirements. Overall, elasticity estimates vary widely-not only between model types, but also among mathematical programming models. Hartman and Whittlesey (1961), in an early study based on representative farms in Colorado, already noted that in addition to factors such as input and output prices, the kinds of adjustments farmers are allowed to make in the model in response to changes in water supply determine the value of additional water, and thus the demand curve shape.

METHODOLOGY

Derived input demand

The prediction of irrigation water demand and price responsiveness are studied extensively since 1960 (Renzetti, 2002). The duality principle lets in representing a firm's technology through the production function, the profit function, or the cost function. Hoteling's Theorem and Shepard's Lemma permitderiving compatible input demands and output with optimization behavior of firms. Therefore, input demands may be regarded as the result of profit maximization or cost minimization. The demand for irrigation water is a derived demand evolving from the value of agricultural products (Scheirling et al,2006). A production structure can be studied empirically the use of both a production function or a cost function. However, the choice should be made on statistical basis (Chembezi, 1990; Kant andNautiyal, 1997). Direct estimation of the production function is more credible in the case of endogenously determined levels of output. In the case of exogenous output levels, the prediction of cost function is preferable (Christensen and Greene, 1976; Mutuku et al, 2009, AbdelhafidhandBachta, 2016). In most cases, agriculture competes with other enterprises for production factors, and this makes price exogenous. Since the arguments of the cost function are output and input prices, its estimation is statistically more consistent than that of the production function. In addition, duality theory permits getting better information regarding the production structure from the cost function. For this research, the direct method approach might be used to predict the water demand function associated with farm products.

The empirical modelof forecasting water demand

Irrigation water demand is estimated using Cobb-Douglas functional form and an econometric analysis method (Arriagada 2004; Nicholson, 2004, Sadeghi, 2010). It is assumed that, under cost minimization, the water demand is a function of the water price P, the per hectare capital factors, (seeds expenditures, treatment products, chemical fertilizers, mechanization costs), land factor (Sup: irrigated area), labour factor L (labour costs) and the per hectare irrigation production value (Z) which explains the physical production and the products prices effects. The irrigation water demand function can be written as follows:

$$Ln(Q)= \beta_0 + \beta_1 ln(P)+ \beta_2 ln(sup)+ \beta_3 ln(S)+ \beta_4 ln(F)+ \beta_5 ln(TR)+ \beta_6 (ME) + \beta_7 ln(L)+ \beta_8 ln(Z)+\varepsilon_i \quad (1)$$

Where:
Q: is the irrigation application rate on the i^{th} farm;
P: is the price of water;
Sup: irrigated area
S: per hectare seeds expenditures
F: per hectare fertilizersexpenditures
TR: per hectare pesticides expenditures
ME: per hectare mechanizationexpenditures
L: per hectare labourexpenditures
Z: per hectare gross product value
ε_i: the disturbance term ~ $N(0, \sigma^2)$.

The estimation of the water demand function will allow to identify the significant variables that explain its consumption, and will provide important information on the factors that influence the use of water in irrigated agriculture in Tunisia. According to the above presented functional form presented above, one should expect a negative impact of the water price. Following the cost minimization problem, the production value (Z) should have a positive impact on water demand.

The average economic water productivity

Production functions are used to predict the crops yield given certain input parameters (Igbadun, et al., 2007).It expresses the relationships between yield and water used. We use the water production function here to predictthe income generated by irrigated crops in Nadhour irrigated area. Production function can be presented as follows:

$$Y= f\ (q, xj) \quad (2)$$

Where (Y) is the output value per farm; (q) is the volume of water (m^3) used per hectare and (x_j) is the amount of other (j) production factors.

Average water productivity (AWP) can be written as follows:

$$AWP = \frac{GM}{q} \quad (3)$$

Where GM: is the gross Margin

AWP gives a useful information about average income generated by one cubic meter of water. However, for a policy maker who may need to proceed changing the water use pattern, this fact isn't always sufficient. Policymakers need information concerning the marginal value of water or the productivity of one-unit-increase (decrease) of water.

Estimation of the production function

The first step in obtaining estimates of the water value is to estimate crop production function. Generally, Cobb-Douglas production functions, are hired in the empirical studies (Wang and Lall, 2002; Young, 2005; Frija et al 2013, Sun et al 2017). Advantages of the Cobb-Douglas function are the parsimony in parameters, the convenience of interpretation, and the computational simplicity (Sahibzada, 2002, sun 2017). The logarithmic form of the production function is as follows:

$$Ln\left(Y_i\right) = \beta_{i0} + B_{i1}Ln\left(q_i\right) + \sum_{j=2}^{j}\beta_{ij}Ln(X_{ij}) + \varepsilon_i \quad (4)$$

Where Ln is the Natural logarithm, (Y_i) is the per farm output value of the i[th] farmer, ε is the error term, (β_0) is a constant and (β_1), (β_j) are parameters of the production function to be estimated. (β_1), also can 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 curried out to the crop.

The OLS resgression is applied to estimate the models (1) and (4). The test of kolmogrov-Smirnov (K-S) was applied to the dependent variables and the probabilities are above the level of 5% meaning that the assumption of the normality of the dependants variables is respected. The K-S test applied to the standardised residual variables show that the errors terms are normally distributed.

The scatter plot of Zresidual and Zpredicted value show that the assumption of homoscedasticity was respected. To test the multicolinearity assumption, the value of inflation factor (VIF) is calculated for all independents variable and all the values are close to level of 2 showing that there is no collinearity between the explonatoryvariables.

The value of marginal product

In most parts of the world, water is not a commodity traded in the marketand its value cannot be directly assessed via market price. Two methods are used to estimate the economic value of water; The value of the marginal product (VMP), which is known as economic returns to water (Shiferaw et al., 2008; Frija et al., 2013), and willingness to pay estimated using contingent valuation (Jaghdani et al. 2012). The VMP of water reflects the shadow price of water, while the contingent valuation method reflects the maximum amount of money that an individual is willing to pay to obtain more units of water. In the current study, we use VMP because it reflects how much value a unit of water adds to crop revenue. This is different from scarcity value, in which an inter-temporal framework is used to capture the value of a water unit conserved for future periods. Considering social and economic importance of irrigated sector in Tunisia, the potential increase of water value used in irrigation is crucial. Indeed, crop choice is essential due to the fact that there may be a variability in needed water and generated income. Thus, substantial economic gains could be made with the aid of reallocating water from lower to higher valued crops (Keller and Seckler, 1996), specifically in areas where water availability is a real constraint such as the case of our study region.

The VMP of water of the i[th] household is defined as:

$$\mathrm{VMP_i} = \frac{\partial \mathrm{Y_i}}{\partial \mathrm{q_i}} \quad (5)$$

Using the definition of output elasticity, VMP can also be expressed as:

$$VMP_i = \epsilon_{Y,q} \cdot \frac{Y_i}{q_i} \quad (6)$$

where is the output elasticity of output Y for irrigation application rate q.

The study area

The research was conducted within the Nadhour irrigated region, sited in the north of Tunisia. Nadhour irrigated area faces growing problems of water scarcity. It is located in the semi-arid bioclimatic lower step with moderate winter. The average rainfall in the area is 400 mm/year with high annual variability and significant evapotranspiration. The agricultural area of Nadhour is around 38.200 ha pooled with 2800 farmers, 60 % of farms area areless than 5 ha and 28 % ranging from 5 to 10 ha. The irrigated systems were installed in 1980 and the irrigated area is around3250 ha. Most irrigated areas are given over to summer crops (watermelon, pepper, melon, season tomato, etc.). The average annual volume of withdrawal water is 14 million cubic meter. Two-thirds of these resources are supplied by groundwater. Water management in the irrigated public perimeters (IPP)is ensured by 24 water users associations(WUAs) counting 1858 farmers and covering 1400 ha. These WUAs are responsible of the water sale to users and the maintenance of water distribution networks. The volumetric pricing method is the most used. The private irrigated perimeters (PIP) cover 1830 ha owned by 933 farmers. Data collection was conducted during spring 2020 from a total sample of 140 farmers, 90 belonging to IPP and 50 to PIP. Face-to-face interviews of farm households were conducted. It particularly concerned basic characteristics of farm households, variable and fixed production costs, farming system characteristics, income, etc.

RESULTS AND DISCUSSION

Descriptive statistics of variables used in the study

Table 1 summarises the main descriptive statistics of variables used for model specification.The average consumed water recordedper farm is 53240m^3 in the PIP and 13954 m^3 in the IPP. This variability is due to the difference between farm sizes belonging to PIP and IPP. The average irrigated area recorded in the PIP is 13.3 ha while it is 3.1 ha in the IPP. The average water price is 0.15 TND/m^{3}in the IPP and 0.17 TND/m^3 in the PIP. The average per hectare gross product recorded is 9333 TND in the PIP and 8603 TND in the IPP.

Water demand results

The regression results are presented in Table 2. The R^2 value of 0.892 for PIP and 0.729 for IPP confirms that 89.2 and 72.6% of the variation in the dependent variable can be explained by the set of explanatory variables included in the model, indicating a good fit to the data, while the significance of the F-statistic (probability = 0.000) suggests that the explanatory variables are statistically significant.

Table 1: Statistical analysis of the study variables

Variables	Private		Public	
	Average	S.D	Average	S.D
Q: Water used/farm (m^3)	53240	47781	13954	15603
Price (cost): TND/m^3	0.17	0.04	0.15	0.04
ME: Mechanization expenditures (TND/ha)	152	101	761	712
S: seeds expenditures (TND/ha)	752	969	536	410
F: Fertilizers expenditures (TND/ha)	490	609	854	1092
TR: Pesticide expenditures (TND/ha)	415	358	430	361
L: Labour expenditures (TND/ha)	1278	649	614	405
Z: Gross product value (TND/ha)	9333	5603	8603	3312
Y: per farm Gross product value (TND)	119413	113439	27229	25907
Sup: Irrigated area (ha)	13.3	11.7	3.1	2.26

The estimated regression coefficient for the water price effect (-0.44 and -0.69 respectively for the PIP and the IPP) is negative and significant at the level of 5%. That means an increase of water price by 10% will decrease water demand by 4.4 and 6.9% in PIP and the IPP respectively. Demand for irrigation water in IPP has larger price elasticity than that in PIP (0.69 versus 0.44). This difference may be explained by the lowest productivity realized by farmers belonging to the IPP. Indeed, when water productivity is low, a little change in water price can induce losses and consequently, farmers may abandon less productive crops, which leads to decreasing irrigation water use. Likewise, the coefficients of seeds are negative and significant at the level of 10% and 5% in PIP and IPP respectively. This also shows that as seed price increases, farmers will not be able to buy reasonable quantities and automatically will decrease the cultivated area. Labourcoefficientis negative and significant. The negative sign of these inputs indicates that seeds, labour, and water input are complementary. The estimated coefficients for production value are positive and significant at a 5% level. Their values are 0.22 and 0.53 respectively in the private and public perimeters. That means to increase total output by 1% we have to increase water use by 0.22% and 0.53% respectively in the PIP and the IPP. This implies a close relationship between revenue and irrigation water demand. When the gross product increases, it allows farmers to have a higher cash flow that encourages them extending irrigated area and increasing irrigation water demand. Results show that irrigated area variation has the most significant effects on consumed water. The corresponding values are 0.77 in the PIP and 0.69 in the IPP. This implies that private farmers are less constrained by area. Thus, as the average farm size is larger in the PIP than that in the IPP, reducing irrigated area in the PIP will have more effect on decreasing the overall irrigation water application. This suggests that policy

Table 2: Estimation results of the water demand function

Variables	Coef.	Private			Public		t-Stat.	P>Z
		Std	t-Stat.	P>Z	Coef.	Std		
(Constant)	6.615	0.720	9.187	0.000	4.069	1.199	3.393	0.001
Ln (P)	-0.440	0.214	-2.055	0.046	-0.695	0.283	-2.455	0.016
Ln (sup)	0.777	0.066	11.784	0.000	0.691	0.095	7.282	0.000
Ln (S)	-0.030	0.016	-1.878	0.068	-0.282	0.094	-3.004	0.004
Ln (ME)	-0.066	0.034	-1.939	0.059	-0.137	0.075	-1.829	0.071
Ln (F)	0.078	0.072	1.080	0.280	0.125	0.051	2.426	0.017
Ln (TR)	0.095	0.039	2.411	0.020	0.117	0.037	3.154	0.002
Ln (L)	-0.155	0.081	-1.907	0.063	-0.080	0.041	-1.964	0.053
Ln (Y)	0.222	0.100	2.213	0.032	0.528	0.181	2.922	0.005
R-squared		0.892				0.729		
Adjusted R^2		0.870				0.702		
F-statistic		41.14				27.26		
Prob (F-statistic)		0.00				0.00		

makers have to regulate groundwater extraction if they want to control water demand. As a result of reducing total irrigated area, policy makers have been anticipating a decrease in irrigation water demand. The decrease in water demand is then, in turn, assumed to benefit from both for the interregional and intraregional water allocation.

Economic returns of irrigation water

The parameters of the CD production function were estimated usingSPSS software. Results of the coefficients and related tests are shown in Table 3. The goodness of fit measures (adjusted R^2) is above 0.8, which is suitable for the range of R^2s observed in other studies that estimate crop production functions. Notably, most input variables have statistically significant coefficients in the two production function regressions. Since the production functions are estimated using log-log forms, the estimated coefficients of irrigation application rates and their interaction terms directly provide the elasticities of production value for irrigation application rates. This elasticity could be defined more clearly as follows: The variation in the productivity of one cubic meter of water allocated to irrigation following a variation in its price (the impact of the variation in the cost of water borne by the operator depending on his valuation of this resource).

This elasticity is quite difficult to interpret intuitively since it is the combined product of two effects that act in opposite directions and therefore compensate each other: Normally when the resource priceincreases, its demand falls. If production following this drop in the allocated volume per hectare remains constant, water productivity increases and we will then have a positive elasticity. However, this increase in the price of the resource would cause another effect that must be explicitly included in the analysis. Indeed, an increase in the resource price would generate an increase in the production cost and therefore a decrease in theallocated water productivity. The final sign of this elasticity, which is the result of these two opposite effects, depends on the importance of each of them.Results show that the output elasticity of production value concerning irrigation water ispositive and statistically significant. This implies that the increase in the allocated water price causes a substantial decrease in water demand without resulting in a significant drop in production. However, findings indicate that production value is more sensitive to water application rate in the private system since the output elasticity of water application is equal to 0.384, in contrast it is equal to 0.287 in the public schemes. According to the diminishing marginal production law, the increase of irrigation application rates will result in the decrease of the marginal product of a crop. This finding will notably affect the value of the marginal product of the applied water.VMPs are imputed by multiplying the output elasticity of the water variable (q_i) estimated in Table 3 with water productivity. Results presented in Table 4 show that the average volume of irrigation water applied per ha is 4012m^3 in the private perimeters in contrast to the applied water rate which is higher in farms inthe public perimeters andit's equal to 4470 m^3. In contrast, the gross product per ha recorded in the private schemes is higher than those recorded in the public schemes. We also remark that water productivity decreases when the total volume of water applied increases.VMPs are reported in Table 4. Average VMPs imputed for the private and public schemes are 0.920 and 0.560 TND/m^3 respectively. The operators who bear the highest cost of the resource, namely the private sector, make better use of the water used than operators supplied by a public network.The lower VMP is due to the higher irrigation application rate. Farms acting in IPP are less efficient in irrigation water use. This may be explained specifically by a change in water supply in these farms.Since economic benefits from increases or decreases in irrigation water are measured as the change in the value of agricultural products and the response of crop yield to various water applications. In the public perimeter, irrigation decisions

Table 3: Coefficients of the production function

Variables	Private				Public			
	Coef.	Std	t-Stat.	Prob	Coef.	Std	t-Stat.	Prob
(Constant)	0.178	1.622	0.109	0.913	3.778	0.617	6.123	0.000
Ln (ME)	0.084	0.042	2.007	0.051	0.137	0.044	3.115	0.003
Ln (S)	0.06	0.020	3.000	0.005	0.230	0.055	4.210	0.000
Ln (F)	0.266	0.084	3.180	0.003	0.074	0.031	2.346	0.021
Ln (TR)	-0.026	0.052	-0.045	0.625	-0.022	0.024	-0.915	0.363
Ln (L)	0.490	0.087	5.628	0.000	0.048	0.026	1.866	0.066
Ln (sup)	0.886	0.093	9.513	0.000	0.966	0.063	15.438	0.000
Ln (q)	0.384	0.181	2.116	0.040	0.287	0.060	4.786	0.000
R^2	0.894				0.883			
Adjusted R^2	0.877				0.875			
F	50.722				90.059			
Prob F	0.00				0.00			

Table 4: Water productivity

	Private	Public
Water applied (m^3/ha)	4012	4470
Gross Margin Value/ha (GM)	6517	5924
Average water productivity (TND/m^3)	2.40	1.94
Average value of marginal product VMP ((TND/m^3)	0,920	0,56
% farms with VMP>Water price	100%	100%

are made by a large number of individual farmers, each representing a small percentage of the total irrigation water used,and these farmers vary widely in management abilities, experience, and farming operationscales.Besides, crop yield response to water application depends strongly on the rate at which water is used with other inputs overs many periods.Irrigation water productivity varies largely over the vegetative cycle depending on soil moisture and the plant's growth stage.

When soil moisture in the plant's root zone is already at maximum level, plant response can be zero or negative. The productivity of added water applied to the plant increases with the time interval (water turn) at which the last moisture occurred. The productivity of added water depletes as well as soil moisture is reduced. Water applied at this critical time is extremely economically valuable. Consequently,the crop yield irrigation water relationship is highly depending on the timing of water applications over the irrigation season. This timing may depend on water governance at the irrigation schemes level, irrigation network state, and the perimeter size or the dependence on the resource system. We also remark that All farms have a higher VMP of water than the price of water. The large gap between water prices and its marginal productivity may explain the low responsiveness of farmers to water price changes. The given information about VMP allows policy makers to identifying affordable limits of any water pricing.

CONCLUSION

In this study, the structure of irrigation water demand in Tunisian' farms was investigated. Irrigation water demand is estimated fora sample of 90 farms from a public irrigated perimeter and 50 farms belonging to the private perimeters at Nadhour district during 2020. Major results of the analysis reveal that the water price significantly influences water consumption. However, farmers are unsensitive to water price change because the irrigation water demand is inelastic. It showed that irrigation water demand is more inelastic in the private perimeter than in public ones. Findings also show that the principal determinants of the irrigation water demand are water price and irrigated area. Results show that water productivity in private perimeters is greater than that recorded in public perimeters. One of the most important findings is that for all farmers the VMPs of irrigation water exceed the prices farmers are paying for irrigation water. Our results indicate that if policy makers were to institute a modest fee for agricultural water use as a mean of reducing demand, the response would be very modest. While overall demand would fall slightly, there would likely be a slight shift in cropping patterns. Any new pricing scheme needs to reflect local and regional circumstances, such as water use, water availability, farm sizes, and crops grown, possible alternative crops, alternative technologies to save water. Results suggested that emphasis should be put on effective and efficient use of water to improve its productivity. The estimated VMPs provide decision makers with some procedure of the minimum required water price's increaseto induce water savings. Furthermore, if possible it would be wise to limit crop production to the only wet season by making more effective use of rainfall. To achieve large-scale yield and water-saving there is a need to develop easy-to-understand water management recommendations for farmers.

Declaration of competing interest

The authors declare no conflict of interest.

Authors' contributions

Hassen Abdelhafidh and Ines Gharbi, conceived and designed the research work, interpreted the data, wrote and revised the manuscript. Collection, analysis and data interpretation performed by Ahlem Maaroufi.

REFERENCES

Abdelhafidh, H. and M. S. Bachta. 2016. Groundwater pricing for farms and water user association sustainability. Arab. J. Geosci. 9: 525.

Abdelhafidh, H. and M. S. Bachta. 2017. Effect of water users associations'financial performances on small farms' productivity. J. New Sci. Agric. Biotechnol. 41: 2211-2222.

Abdelhafidh, H., A. Fouzai, A. Bacha and M. Ben Brahim. 2021. To what extent corruption and free-riding behavior affect technical and water use efficiency of small-scale irrigated farms. New Medit. 20: 3-14.

Abdelhafidh, H., M. Ben-Brahim, A. Bacha and A. Fouzai. 2022. Farmers' willingness to pay for irrigation water: Empirical study of public irrigated area in a context of groundwater depletion. Emir. J. Food Agric. 34: 44-50.

Arriagada, R. A. 2004. Estimating Profitability and Fertilizer Demand for Rice Production around the Paloverde National Park, Costa Rica. (Doctoral Dissertation). North Carolina State University, Raleigh.

Bachta, M. S., A. Ben Mimoun, L. Zaiebet and L. Albouchi. 2004. Simulation of a Water Market in Tunisia: Case Study of GIC Melalsa-Kairoun. In Cirad-00189532, Version 1. The Modernization of Irrigated Agriculture: In: Seminar Proceeding, Rabat,Marocco. p.14. Available from: https://www.hal.cirad.fr/cirad-00189532

Berbel, J. and J. A. Gómez-Limón. 2000. The impact of water-pricing policy in Spain: An analysis of three irrigated areas. Agric. Water Manage. 43: 219-238.

Butler, D. and F. A. Memon. 2006. Water Demand Management. IWA Press, London, UK.

Chebil, A., A. Frija, and C. Thabet. 2010. Irrigation water pricing between governmental policies and farmers' perception: Implications for green-houses horticultural production in Teboulba (Tunisia). Agric. Econ. Rev. 11: 44-54.

Chembezi, D. M. 1990. Estimating fertilizer demand and output supply for malawi's smallholder agriculture. Agric. Syst. 33: 293-314.

Christensen, L. R. and W. H. Greene. 1976. Economies of scale in US electric power generation. J. Poli. Econ. 84: 655-675.

Dolatyar, M. and T. Gray. 2000. Water Politics in the Middle East: A Context for Conflict or Cooperation? Palgrave Macmillan. Basingstroke, New York.

Frija, A., A. Chebil and H. Cheikh-M'Hamed. 2013. Marginal value of Irrigation Water in Wheat Productionsystems of Central Tunisia. In African Association of Agricultural Economists(AAAE). In: Proceeding of the Fourth International Conference, Hammamet, Tunisia. p.1-17. Available from: https://www.ideas.repec.org/p/ags/aaae13/160525.html

Frija, A., A. Wossink, J. Buysse, S. Speelman and G. Van Huylenbroeck. 2011. Irrigation pricing policies and its impact on agricultural inputs demand in Tunisia: A DEA-based methodology. J. Environ. Manage. 92: 2109-2118.

Garrone, P., G. Luca and M. Riccardo. 2019. Price elasticity of water demand considering scarcity and attitudes. Utilit. Policy. 59: 100927.

Grafton, R. Q., L. Chu and P. Wyrwoll. 2020. The paradox of water pricing: Dichotomies, dilemmas, and decisions. Oxford Rev. Econ. Policy. 36: 86-107.

Hartman, L. M. and N. Whittlesey. 1961. Marginal Values of Irrigation Water: A Linear Programming Analysis of Farm Adjustments to Changes in Water Supply. Tech. Bull. No. 70. Agricultural Experiment Station. Colorado State University, Fort Collins.

Huang, Q., J. Wang and Y. Li. 2017. Do water saving technologies save water? Empirical evidence from North China. J. Environ. Econ. Manage. 82: 1-16.

Huang, Q., S. Rozelle, R. Howitt, J. Wang and J. Huang. 2010. Irrigation water demand and implications for water pricing policy in rural China. Environ. Develop. Econ. 15: 293-319.

Igbadun, H. E., A. K. P. Tarimo, B. A. Salim and H. F. Mahoo. 2007. Evaluation of selected crop water production functions for an irrigated maize crop. Agric.Water Manage. 94: 1-10.

Jaghdani, T. J., B. Brümmer and J. Barkmann. 2012. Comparison of methods for the valuation of irrigation water: Case study from Qazvin, Iran. Irrig. Drain. 61: 375-385.

Jeder, H, E. B. Hamza and H. Belhouchette. 2019. An optimal price for sustainable irrigatedagriculture in central-eastern Tunisia. New Medit. 18: 3-13.

Jeder, H., A. Ben Khalifa and M. Sghaier. 2014. Economic analysis of water demand in publics irrigationsystems in Tunisia, using FSSIM model. New Medit. 13: 46-53.

Kant, S. and J. C. Nautiyal. 1997. Production structure, factor substitution, technical change, andtotal factor productivity in the Canadian logging industry. Canad. J. Forest Res. 27: 701-710.

Katz, D. 2016. Undermining demand management with supply management: Moral hazard in Israeli water policies. Water. 8: 159.

Keller, A., J. Keller and D. Seckler. 1996. Integrated Water Resource Systems: Theory and Policyimplications. Research Report 3. International Water Management Institute, Colombo, Sri Lanka.

Mahdhi, N., M. Sghaier and Z. Smida. 2014. Efficiency of the irrigation water user association in the Zeuss-Koutine region, South-Eastern Tunisia. New Medit. 13: 47-55.

Moore, M. R., N. R. Gollehon and M. B. Carey. 1994. Multicrop production decisions in western irrigated agriculture: The role of water price. Am. J. Agric. Econ. 76: 859-874.

MutukuMuendoKavoi, D. L. Hoag and J. Pritchett. 2009. Production structure and derived demand for factor inputs in smallholder dairying in Kenya. Afr. J. Agric. Res. Econ. 3: 122-143.

Nicholson, C. F., K. T. Philip and R. W. Mungai. 2004. Household-level impacts of dairy cow ownership in coastal Kenya. J. Agric. Econ. 55: 175-195.

Renzetti, S. 2002. The Economics of Water demands. Natural Resource Management and Policy Series, Kluwer Academic Publishers, Boston.

Sadeghi, A., M. G. Mohaydin, M. A. Hussein and J. Attari. 2010. Estimation of irrigation water demand for barley in Iran. The panel data evidence. J. Agric. Sci. 2:31-40.

Sahibzada, S. A. 2002. Pricing irrigation water in Pakistan. An evaluation of available options. Pak. Dev. Rev. 41: 209-241.

Salman, A. Z. and E. Al-Karablieh. 2004. Measuring the willingness of farmers to pay for groundwater in the highland areas of Jordan. Agric. Water Manag. 68: 61-76.

Scheierling, S. M., J. B. Loomis and R. A. Young. 2006. Irrigation water demand: A meta-analysis of price elasticities. Water Resour. Res. 42: 1411.

Shiferaw, B., V. R. Reddy and S. P. Wani. 2008. Watershed externalities, shifting cropping patterns and groundwaterdepletion in Indian semi-arid villages: The effect of alternative water pricing policies. Ecol. Econ. 67: 327-340.

Sun, T., Q. Huang and Q. Wang. 2017. Estimation of irrigation water demand and economic returns of water in Zhangye basin. Water. 10: 19.

Varela-Ortega, C., J. M. Sumpsi, A. Garrido, M. A. Blanco and E. Iglesias. 1998. Water pricing policies, public decision making and farmers' response: Implications for water policy. Agric. Econ. 19: 193-202.

Young, R. A. 2005. Determining the Economic Value of Water: Concepts and Methods, Illustrated Edition. RFF Press:Washington, DC.