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Abstract

The main objectives of this paper are to evaluate the impact of water use efficiency improvement on water value and to estimate the potential of water cost reductions in durum wheat production in Central Tunisia. Results show that significant inefficiencies exist in the sample of farms under investigation. The effects of technical efficiency on marginal values of water applied for irrigation could shift the marginal value of the water curve upwards, thereby raising water value. By operating at full water economic efficiency levels, the sampled farms would be able to reduce their water costs of wheat production by about 42%. Technical efficiency and allocative efficiency levels account respectively for 61% and 39% of the total water cost reductions. Results of the Tobit model estimation indicate a positive effect of farm size, irrigation sources, membership in water users association, pesticide application, and irrigation scheduling on the economic water efficiency. This suggests that there is a potential to improve production efficiency through enhancement of extension services to the small size farmers, and further encouragement of farmers to adhere to the water users' associations.

JEL Classification: C12, I73, J46, O35

***Keywords*:** Water use efficiency; Water value; Durum wheat production, Central Tunisia.

ملخص

تهدف هذه الورقة الى تقييم تأثير تحسين كفاءة استخدام المياه على قيمة المياه وتقدير إمكانات تخفيض تكلفة المياه في إنتاج القمح القاسي في تونس الوسطى. وتشير النتائج إلى أن عدم وجود كفاءة كبيرة في عينة من المزارع قيد التحقيق. نجد أيضا أن آثار الكفاءة الفنية على القيم الحدية للمياه بطلب الحصول على الري قد تغير القيمة الحدية لمنحنى المياه صعودا، وبالتالي رفع قيمة المياه. من خلال العمل على مستويات الكفاءة الاقتصادية للمياه كاملة، فإن عينات المزارع قد تكون قادرة على خفض تكاليف المياه فى إنتاجها من القمح بنسبة 42٪. وخفض التكاليف الكفاءة الفنية ومستويات الكفاءة التخصيصية وتمثل على التوالي 61٪ و 39٪ من إجمالي المياه. نتائج تقدير نموذج Tobit تشير إلى الأثر الإيجابي لحجم المزرعة، ومصادر الري، والعضوية في جمعيات مستخدمي المياه، استخدام المبيدات، وجدولة الري على كفاءة استخدام المياه الاقتصادية. يشير هذا كله إلى أن هناك إمكانية لتحسين كفاءة الإنتاج من خلال تحسين خدمات الإرشاد للمزارعين الصغار ، ومواصلة تشجيع المزارعين على الانضمام إلى جمعيات مستخدمي المياه.

1. Introduction

The cereal sector is considered a strategic sector in Tunisia. It provides major staple food commodities for most Tunisian households. Cereals are cultivated on almost one third of the agricultural areas (1.5 million hectares) and create 13% of the total agricultural value added. Cereal productivity in the country remains very low compared to its potential and the updated average yield per hectare is below 1.3 tons/ha (MA 2010). Consequently, Tunisia imports approximately 3 million tons (INS 2010) to meet the domestic demand for cereals. Improvement of cereal productivity in Tunisia has become a responsibility for policy makers who need to reduce the import of this commodity.

Wheat is one of the main cereals produced in Tunisia in terms of its output and cultivated land area. It occupies about 50% of all cereal-cultivated areas (800,000 ha on average) and represents almost 55% of the total cereal production (MA 2010). Currently, irrigated wheat area is around 80,000 ha (MA 2011). This sub-sector faces a lot of challenges such as food security, sustainability of the cultivated areas, limited water resources for irrigation and an arid climate characterized by frequent drought. The use of irrigation is proposed as a main solution to improve yields. In this context, emphasis was placed on the extension and development of irrigated areas as an alternative for achieving this goal. Although the area of irrigated wheat has increased from 47,500 ha in 1998 to 80,000 ha in 2012 (MA 2011), wheat yield in irrigated areas is still at around 3.8 tons/ha since 1997 (INGC 2012). However, in Tunisia there is limited scope for further increase in the use of land and water resources for extension of the cereal sector. In fact, fresh water mobilization has reached its limits and any further investments for water mobilization will be very costly. Therefore, future increases in irrigated wheat production need to originate from improvements in performance of wheat farms. Most studies in Tunisia on water-use efficiency show that water is still used inefficiently at the farm level (Dhehibi et al. 2007; Albouchi et al. 2007; Frija et al. 2009; Naceur et al. 2010; Chemak et al. 2010; Chemak and Dhehibi 2010; Chebil et al. 2012; Chebil et al. 2013). Low irrigation efficiency is associated with technical and allocative inefficiencies. This is in contrast with the present situation in Tunisia where water scarcity is increasing. The water price is heavily subsidized and there is little or non-incentive to economize in using this production resource, implying the tendency of farmers to over-irrigate their crops. The growing scarcity and rising costs of water have led to the realization that water has to be allocated and used more efficiently. If the price of water is below its real cost, it will be used inefficiently.

The main objectives of this study are to evaluate the impact of improving the water-use efficiency on water value and to estimate the potential of water cost reductions in durum wheat production in Central Tunisia.

The remainder of this paper is organized into six sections. Section 2 presents the conceptual framework adopted in this study. Section 3 presents the methodology and data. Results and discussion are presented next. Conclusions and policy implications of the study are presented in the last section.

2. Conceptual Framework: Economic Efficiency, Water Value and the Frontier

Economic efficiency is divided into technical and allocative efficiency. Technical efficiency can be defined as producing a maximum amount of output, for a given set of inputs (output-oriented) or producing a given level of output using a minimum level of inputs (input-oriented). Hence, the production function describes a frontier. If the production frontier is known, the technical inefficiency of any particular firm can be assessed easily by simply comparing the position of the firm relative to the frontier (Coelli 1995). Allocative efficiency (AE) is reached when the value of marginal product (VMP) of each input is equal to its unit cost Farell (1957).

Technical and allocative inefficiency can be illustrated with the aid of figure 1, using output (Y) and input (water). The production frontier for a firm using best practice techniques (efficient situation) is shown by frontier F. At points B and C, the firms are technically efficient in the sense that they are in the production frontier F, and there is no way to obtain more output without using more input. A firm operating at point C on the frontier uses W* level of water and receives profit max π (c) (where the iso-profit line is tangential to its production frontier) is economically efficient. On the other hand, the firm operating at point B on the frontier F uses W_i level of water and receives lower profits π (B) than C. This loss of profit is due to allocative inefficiency.

However, firms do not operate at their best practice output curve F, but rather at a lower frontier f' (current situation). At point A, the firm experiences both allocative and technical inefficiency. A movement to production point B, in that more output could be obtained with no more input, would leave the firm technically efficient but still allocatively inefficient as profit could be raised further to level C. In terms of profit loss, a firm operating at A, experiences a shortfall in profit given by π (C) - π (A). Of this total shortfall, π (B) - π (A) is attributed to technical inefficiency and π (C) - π (B) is attributed to allocative inefficiency.

The curves of marginal water value for inefficient water use (VMP_{INTEC}) and enhanced efficient water use (VMP_{TEC}) are also illustrated in figure 1. The difference between the marginal water values in the two situations is equal to the loss of water value associated to the technical inefficiency. However, the allocative inefficiency is given by the difference between the marginal value of water and the price of water.

The economic efficiency (EE) of one input (water) is decomposed into two components: Technical efficiency (TE) and water allocative efficiency (WAE) (Coelli et al. 2007). All these efficiency measures take a value ranging from zero to one. Water EE is determined by the product of TE and WAE (EE= ET*WAE).

3. Methodology

The methods of analysis used in this study are Data Envelopment Analysis (DEA), the Stochastic Production Frontier and the Tobit model.

3.1 Data Envelopment Analysis (DEA)

The DEA model has been frequently applied in agriculture due to its advantages. Charnes, Cooper and Rhodes (CCR) (1978) proposed a model which was input oriented and assumed constant returns to scale (CRS). Banker, Charnes and Cooper (BCC) (1984) suggested an extension to the CRS DEA model to reflect the variable returns to scale (VRS) situation. The use of the CRS specification when not all farms are operating at the optimal scale will result in measures of TE which are confounded by scale efficiencies (SE).

In the present analysis, we use an input oriented DEA model where the estimated efficiency scores typically indicate how much a farm should be able to reduce the use of all of its inputs as compared to the best performers.

Suppose data on K inputs and M outputs for each of N farms. For farm *i*, input and output data are represented by the column vectors x_i and y_i, respectively. The KxN input matrix X and the MxN output matrix Y represent the data for all N farms in the sample. The DEA model to calculate TE is given by equation 1 and the input-oriented formulation of the BCC model can be represented as follows.

$$Min_{\theta\lambda}\theta, \qquad (1)$$

$$
\begin{aligned}
& -y_i + Y\lambda \geq 0, \\
& \theta x_i - X\lambda \geq 0, \quad \text{subject to} \\
& N1'\lambda = 1, \\
& \lambda \geq 0
\end{aligned}
$$

With θ being a scalar, *N1* is an *Nx1* vector of ones, and λ is an *Nx1* vector of constants. This model is solved for each farm once, in order to obtain a value for θ. This value, between zero and one, is the TE score for farm *i*. It should also be noted that equation (1) has a VRS specification which includes a convexity constraint ($N1'\lambda=1$). Without that constraint (CCR model), equation (1) represents a CRS specification which assumes that farms are operating at their optimal scale. A measure for scale efficiency is given by dividing the technical efficiency score in the CRS specification by the score in the VRS specification ($SE = TE_{CRS}/ TE_{VRS}$). That is, the CRS technical efficiency measure is decomposed into pure TE and SE.

3.2 Stochastic production frontier

The Cobb-Douglass stochastic production frontier is used for this empirical analysis. It is given by

$$Y_i = A.W_i^{\beta_0} \prod_{k=1}^{k} X_{ki}^{\beta_k} e^{\varepsilon_i} \tag{2}$$

Where *Yi* is the output of the *i*th farm , A is the intercept, W_i is the volume of supplied water (rain + irrigation) , X_{ki} is the *k*th input, and $\beta_o,\ldots\ldots\beta_k$, are the coefficients for water and the other inputs, respectively. The error term, ε_i, of the model is composed of two independent elements (Aigner et al. 1977):

$$\varepsilon_i = v_i - \mu_i \tag{3}$$

Where v_i is the symmetric disturbances assumed to be identically, independently and normally distributed as N(0, σ_v^2); and μ_i is a one sided component, where $\mu_i \geq 0$ reflects technical efficiency relative to the stochastic frontier. It is assumed that U is identically and independently distributed as N(0, σ_u^2). The maximum likelihood estimation for equation (2) provides estimators for β and variance parameters $\sigma^2 = \sigma_v^2 + \sigma_u^2$, as well as $\gamma = \frac{\sigma_u^2}{\sigma^2}$.

The coefficient β_o can be considered as the output elasticity of the variable water. The value of marginal product for water can be written as follows: The marginal value of water estimated as the variation of the output value due to a given change of the water use

$$VMP_w = P_Y \frac{\partial Y}{\partial W} \tag{4}$$

Where P_Y is the unit price of the output. Allocative efficiency is determined by comparing the VMP_w with the market price of water (P_w). If $VMP_w>P_w$, water is underused and farm profits can be raised by increasing the use of water. If, conversely, $VMP_w<P_w$, the water is overused and to raise farm profits its use should be reduced. The point of allocative efficiency (and maximum profit) is reached when $VMP_w=P_w$.

3.3 The Tobit model

The present study uses the Tobit model to analyze the role of farm attributes in explaining the EE of water. This approach has been used widely in efficiency literature (Speelman et al. 2008; Naceur et al. 2010; Chebil et al. 2012). In fact, the values of the dependent variable lie in the interval (0,1). The censored Tobit model can be then used to get a consistent estimation. The Tobit model used in our study is specified as follows:

$$EE_i = \begin{cases} EE_i^* \; if \; 0 < EE^* < 1 \\ 0 \; if \; EE^* \leq 0 \\ 1 \quad if \;\; EE^* \geq 1 \end{cases} \tag{5}$$

Where EEi the observed dependent variable for the ith farm; EEi* is an unobserved latent variable for the ith IWUE farm that is observed for values greater than 0 and censored for values less than or equal to 1.

$$EE^* = X_i \beta + \varepsilon_i \tag{6}$$

Where Xi is a vector of independent variables supposed to influence efficiency. The βs are parameters associated with the independent variables to be estimated. The ε is the independently distributed error term assumed to be normally distributed with a mean of zero and a constant variance $N(O,\sigma^2)$. Since the dependent variable of EE varies between 0 and 1, Least Ordinary Square (LOS) would produce biased and inconsistent estimates (Maddala 1983). Therefore, the maximum likelihood estimation is recommended for the Tobit analysis.

4. Study Region, Data and Variables Definitions

The delegation of Chebika occupies a central area in the governorate of Kairouan, which is located in the center of Tunisia. This region is characterized by a high number of cereal farms. Cereals occupy 16,920 ha in Chebika and represent 33% of the total agricultural area of which 12,750 ha are rain-fed and 4,170 ha are irrigated. Irrigated cereals, despite limited areas (24.64% of area under cereals), provides the largest share of cereal production Chebika (63.7%). It is important to note that the delegation of Chebika is the leading producer of cereal by irrigation in the governorate of Kairouan (CTV 2012). Chebika is facing growing problems of water scarcity. It is located in the semi-arid bioclimatic lower floor and characterized by a moderate winter. The rainfall during the growing season 2010-2011 was about 290 mm. However, groundwater represents the main water source.

The data used in this study was collected from 170 Tunisian wheat farms, which cultivated irrigated durum wheat during the agricultural season 2010-2011. The total number of wheat farmers in the region of Chebika was around 1,000, which means that our sample is highly representative. The sample used was stratified per area and farmers were randomly selected in each area. The survey was conducted in 2012, and farmers were selected with the collaboration of the extension service in the region.

Wheat production value per ha is used as output. Five inputs: water (W), seeds (S), chemical fertilizer (F), labor (L) and machinery (M) are used in the estimation of the production function and the DEA model. Elements of descriptive statistics relating to inputs, outputs and farm-specific variables are presented in Table 1. The volume of irrigation water applied per hectare varies between farmers. It ranges from 500 m^3/ha to 6,000 m^3/ha. The sample average is 2,700 m^3/ha. The average production value per ha in our sample is equal to TND2,226.26, corresponding to an average yield of 3.9 tons/ha.

5. Empirical Results

5.1 Efficiency scores results

The estimation of efficiency scores by the DEA was conducted by the DEAP (Data Envelopment Analysis Program) software. Distribution of technical efficiency of cereal farms in the region is summarized in table 2. The estimated efficiency measures reveal a significant TE of production in our sample of wheat farms. The computed average TEs under CRS and

VRS are 70.7% and 82.0%, respectively. The average SE is about 86.5%. The DEA results reveal a wide variation in individual efficiency scores across farms, ranging from 100% to 28%. Given the present state of technology and input levels, this suggests that farms in the sample are using 30% more inputs to produce the current level of output.

Results under CRS show that 5.9% of farms have technical efficiency scores that are less or equal to 50%; 71.8% of those have an efficiency between 50% and 80% and 23.3% of the farms have a TE strictly greater than 80%. These results provide, on one hand, information about the heterogeneity of farm performances, and on the other hand, the potential for increasing wheat production, in Chebika.

5.2 Empirical estimation of stochastic production frontier

The parameters of the Cobb-Douglas stochastic production frontier were estimated using the computer program Frontier 4.1. (Coelli 1996). Results of the coefficients and related tests are shown in table 3. The signs of the estimated parameters are as expected. Estimated coefficients are positive and statistically significant at the 5% level for the majority of independent variables. The variance parameter of the model (γ) is significantly different from zero at the 5% level, which means there are inefficiencies in production.

Estimated partial production elasticities with respect to the production factors are indicated in table 3.The value of these elasticities for water, seeds, chemical fertilizers, labor and machinery are 0.27, 0.15, 0.12, 0.16 and 0.27, respectively.

Using the estimated parameters of the production frontier, we calculate 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. One can see from figure that VMP falls as water is applied, which is consistent with the usual assumptions economists make regarding falling marginal physical product. 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.

The effects of technical efficiency on marginal values of water applied for irrigation is illustrated in figure 2. It should be noted that an improvement of technical efficiency could shift the VMP curve upwards, thereby raising VMP.

The average WAE and EE are 81.58% and 55.05%, respectively (table 4). Thus, both results reveal substantial inefficiencies of the farms in Chebika. We note that 25.29 of farms have EE scores that are less than 50%, besides, 67.65% have efficiency scores between 50% and 80% and only 7.06% of farms have an EE strictly greater than 80%.

5.3 Tobit model

Tobit regression explaining efficiency, as defined in equation 4 is estimated using Eviews (econometric views) package version 8. The results of the Tobit model estimation by maximum likelihood are shown in Table 5.

Regarding the Tobit model results, the likelihood ratio test rejects a null hypothesis that all slope parameters are simultaneously null. This confirms that the Tobit model is statistically valid. Results also indicate that the majority of the estimated coefficients are significant at 10% level. Furthermore, the estimates of the model indicate a positive effect of water sources, farm size, pesticide application, farmers' membership in water users association, and irrigation scheduling on EE of water.

Based on the empirical results, some suggestions such as reducing land fragmentation, encouraging farmers' associations, dissemination and setting up training programs on irrigation scheduling, and improvement of extension services are needed in order to increase the EE of water in the region.

6. Discussion

The empirical results show that significant irrigation water use inefficiencies of wheat production exist for our farm sample. This means that there is potential to reduce water costs. Our results are in line with other case studies in Tunisia which were interested in the calculation of water use efficiency in irrigated Farms (Dhehibi et al. 2007; Albouchi et al. 2007; Frija et al. 2009; Naceur et al. 2010; Chemak 2010; Chemak and Dhehibi 2010; Chebil et al. 2012, Dhehibi et al. 2012; Chebil et al. 2013). A few authors were focused on measuring cereal farms' technical efficiency in Tunisia (Bachta and Chebil 2002; Dhehibi et al.2012; Chebil et al. 2013) and they also found that there is a large potential to increase this efficiency indicator.

However, to our knowledge, no studies were focused on water AE and EE. Our study confirms the possibilities of productivity gains by improving the AE and EE of water. The potential for water cost reductions at the fully efficient level is reported in table 6. On average, farmers in our sample are able to reduce their current costs of water by 42%, without harming their production levels. As shown in table 6, TE and water AE levels account respectively for about 61%, and 39% of the total cost reductions.

7. Conclusion and Policy Implications

This paper investigates the impact of water use efficiency improvement on water value and the potential of water cost reductions in durum wheat production in Central Tunisia. To this end, Data Envelopment Analysis, Cobb- Douglas and Tobit models were used.

Results show that significant inefficiencies exist in the sample of farms under investigation. The average technical efficiencies estimated under constant returns to scale and variable returns to scale hypothesis of the farms in the sample are 0.70 and 0.82. This implies that the current level of output can be produced using 30% less inputs, on average. Most farmers are applying either lower or higher volumes than the economic optimum dose. The average water allocative efficiency of water is about 0.82. The water value is highly affected by water use efficiency.

The simulation results of improving technical efficiency on marginal values of water applied for irrigation show that the value marginal product curve upwards, thereby raising water value. By operating at full water economic efficiency levels, the sampled farms would be able to reduce their costs of wheat production by about 42%. Technical efficiency and allocative efficiency levels account respectively for 61% and 39% of the total water cost reductions.

Results of the Tobit model indicate a positive effect of water sources, farm size, pesticide application, membership in water users' association, and irrigation scheduling on the EE of water. This suggests that there is potential to improve production efficiency through enhancement of extension services to the small-size farmers, and further encouragement of farmers to adhere to the water users' associations. The last measures could easily help sprea the information about irrigation water scheduling and doses among farmers.

Finally, it should be noted that our analysis is based on information of farms in one region. Additional research with panel data would be more scientific and reasonable.

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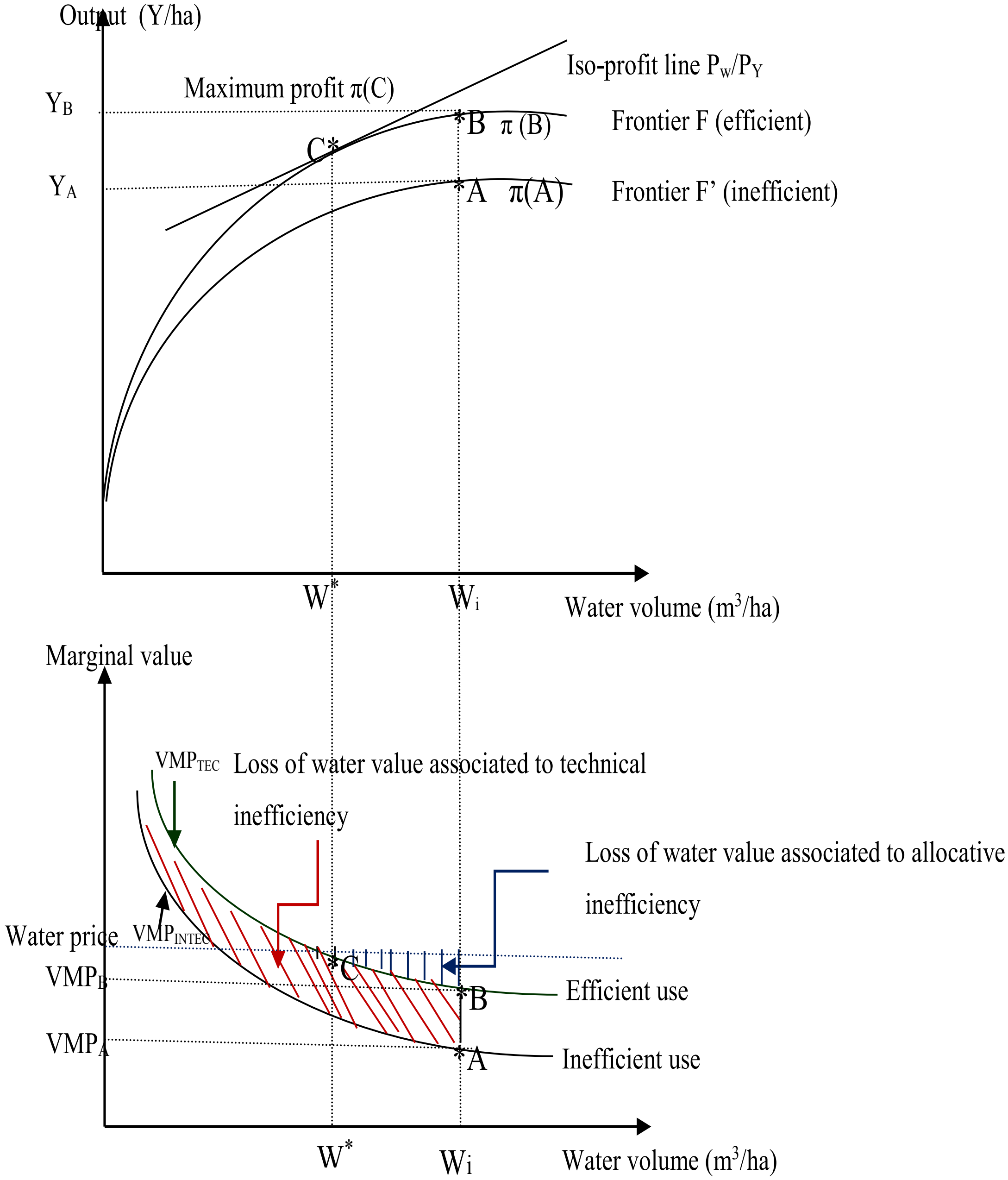
Figure 1: Technical, Allocative Inefficiency and Marginal Water Value



Source: Own elaboration

Figure 2: Curves of Marginal Water Value (Different Scenarios of Improving Technical Efficiency)

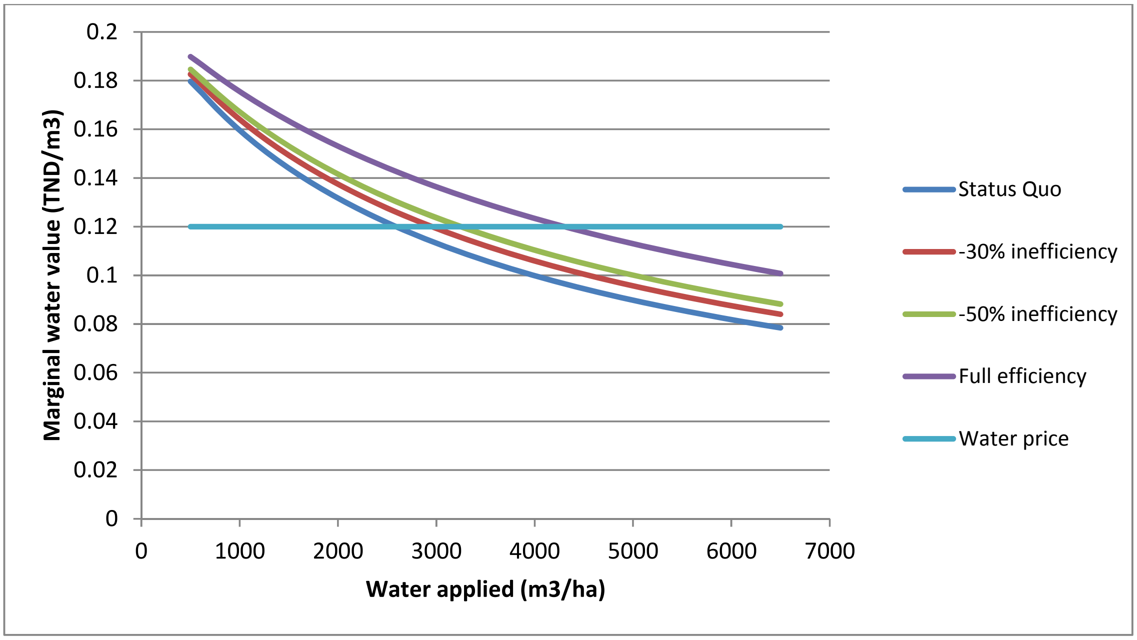


Table 1: Summary Statistics of the Variables Used in the Analysis of Efficiency

Variable		Mean	SD.	Min	Max
Output	Output value (TND/ha)	2226.26	636.46	1016.00	4370.00
Inputs	Applied water (m3/ha)	2696.24	1110.80	500.00	6000.00
	Seeds (TND/ha)	114.22	31.71	55.00	154.00
	Chemical fertilizer (TND/ha)	142.23	60.02	33.00	338.00
	Labor (TND/ha)	66.46	22.30	31.50	178.75
	Machinery(TND/ha)	378.26	117.41	165.00	1300.00
Farm-specific factors	Age (years)	50.43	13.19	22.01	86.00
	Education level (1 if farmer has more than secondary level, 0 otherwise)	0.27	0.44	0	1
	Experience (years)	25.78	13.05	2.00	60.00
	Size (total cropping area in ha)	14.01	13.34	1.20	95.00
	Water source (1 if the farmer uses two sources, 0 if one)	0.04	0.19	0	1
	WUA (1 if farmer is member, 0 otherwise)	0.36	0.48	0	1
	Irrigation management (1 if farmer respects the critical period, 0 otherwise)	0.37	0.49	0	1
	Wheat variety (1 if farmer uses Maali variety, 0 otherwise)	0.35	0.48	0	1
	Pesticide (1 if farmer uses pesticide, 0 if not)	0.42	0.49	0	1

Table 2: Frequency of Distribution of Technical Efficiency Estimates

	CRS	SE	VRS
TE≤50 (%)	*5.9*	*0.6*	*0.6*
50<TE≤80 (%)	*71.8*	*31.7*	*42.9*
TE>80 (%)	*22.3*	*67.7*	*56.5*
Mean (%)	**70.7**	**86.5**	**82.0**
Min (%)	**27.9**	**46.5**	**48.9**
Max (%)	**100**	**1**	**1**
Std. dev.	**14.9**	**13.1**	**13.6**

Table 3: Maximum Likelihood Estimates of the Cobb-Douglass Stochastic Production Frontier

	Coefficients	t-stat
Cte	1.96	3.11***
W	0.27	3.98***
S	0.15	1.78*
F	0.12	2.70***
L	0.16	2.18*
M	0.27	2.77***
σ^2	0.08	5.69***
γ	0.75	8.32***
Log-likelihood	32.31	
Number of observations	170	

Note: ***, **,* indicate significance at 1%, 5% and 10%, respectively.

Table 4: Frequency of Distribution of Water AE and EE Estimates

	AE	EE
TE≤50 (%)	1.18	25.29
50<TE≤80 (%)	37.64	67.65
TE>80 (%)	61.18	7.06
Mean (%)	81.58	58.05
Min (%)	47.03	13.43
Max (%)	99.69	99.69
Std. dev.	10.82	15.14

Table 5: Tobit Estimation Results of Factors Affecting Water Economic Efficiency Scores

Variables	Coefficient	Z-Statistics
Age	-0.004	-0.432
EL	-0.02	-0.876
EXP	0.001	0.148
SIZE	0.001	1.768*
WS	0.210	3.851***
GDA	0.049	1.920**
IRR	0.084	3.117***
VAR	0.005	0.214
PES	0.050	1.884**
C	0.503	9.784***
LR1	47.696*	

Note: ***, **,* indicate significance at 1%, 5% and 10%, respectively

Table 6: Potential of Water Cost Reductions in Wheat Production

	Observed cost	Potential of water cost reductions at full efficiency levels		
		Technical	Allocative	Total
Water cost (TND/ha)	296.60	75.95	48.47	124.43
% of the Total		61.04	38.96	100

[1] $LR = -2(\log L_r - \log L_u)$ where $LogL_u$ is the log-likelihood for the unrestricted model and $LogL_r$ is the log-likelihood for the model with p parameters restrictions imposed. The likelihood ratio statistic follows a chi-square distribution with p degrees of freedom.