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Optimizing Water Use Efficiency in Arid Tunisia: An Economic Evaluation of Public Irrigated Schemes for Agricultural Development

Optimisation de l'efficacité de l'utilisation de l'eau dans la Tunisie aride : une évaluation économique des périmètres publics irrigués pour le développement agricole.

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Résumé

Cet article examine les déterminants de l'efficacité technique et de l'utilisation de l'eau dans des périmètres irrigués dans une région aride de la Tunisie. Les données ont été collectées auprès de 92 exploitations agricoles situées dans des périmètres irrigués. L'analyse des enquêtes a été réalisée par la méthode d'analyse d'enveloppement des données (DEA) pour le calcul des scores de l'efficacité, puis le modèle Tobit a été utilisé pour identifier les déterminants. Les résultats montrent que les scores moyens pour l'efficacité de l'utilisation de l'eau sont respectivement de 54% et 68% sous les hypothèses de rendements d'échelle constants (CRS) et de rendements d'échelle variables (VRS). L'étude met en évidence que plusieurs facteurs tels que les tours d'irrigation ou la périodicité de l'irrigation, l'entraide agricole, le choix de cultures adaptées et la réduction de l'irrigation par submersion affectent positivement et significativement le niveau de l'efficacité de l'utilisation de l'eau. Les auteurs concluent que pour améliorer l'efficacité du secteur agricole irrigué, il s'agit de de promouvoir l'agriculture familiale et l'entraide agricole, améliorer les tours d'eau d'irrigation et utiliser des cultures et des variétés adaptées.

Mots-clés : irrigation, efficacité, analyse d'enveloppement des données (DEA), modèle Tobit, Tunisie.

Abstract

This paper investigates the determinants of efficiency in the irrigated sector of an arid region in Tunisia. The study evaluates water use and technical efficiencies and identifies the factors that influence these efficiencies. Data was collected from a sample of 92 farms in irrigated areas and analyzed using data envelopment analysis (DEA) and censored regression methods. The results indicate that the average scores for water use efficiency (WUE) are 54% and 68% under constant return to scale (CRS) and variable return to scale (VRS) assumptions, respectively.

The study finds that several factors such as irrigation water turns, family mutual assistance between farmers, selecting more suitable crops, and reducing flood irrigation significantly and positively affect the level of water use efficiency. The authors conclude that promoting small-scale family farming, improving irrigation water turn, and adapting cropping systems to local conditions are necessary to enhance the efficiency of the irrigated agriculture sector.

Keywords: Irrigation; efficiency; DEA; Tobit model; Tunisia

African Scientific Journal
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Introduction

In the face of global climate change, the issue of water scarcity has emerged as a serious concern with far-reaching implications for food security. The imperative to increase agricultural productivity by enhancing water use efficiency (WUE) has been widely recognized as essential, as noted by Nahmo et al. (2016). Despite the commitment of all nations to the Sustainable Development Goal (SDG) 6, which aims for universal access to safe water, a significant proportion of the global population continues to lack access to it. Water scarcity poses a significant challenge to global food security and is a major obstacle to achieving SDG 2 (Zero Hunger), as a result of poor water management and inefficient irrigation practices. Improving WUE in agriculture is essential for increasing crop yield per unit of water consumed, ensuring food security, and minimizing the strain on limited water resources. Efficient irrigation techniques, crop selection, and precision farming practices play a vital role in enhancing agricultural WUE (Ahmad et al., 2009).

Significant water mismanagement has been observed, with evaporation and inefficient use being major contributors to the problem, despite increasing demand for water in agricultural production, as highlighted by Fleiner et al. (2013). Addressing water scarcity and improving water management is thus essential for achieving sustainable development goals and ensuring global food security.

Moreover, the development of technical efficiency in agriculture and rural economies is essential to improving living standards and reducing poverty in agricultural and rural areas, as highlighted by Bojnec et al. (2014). Economists have recognized that the efficient use of resources at the farm level is a major concern, especially in less developed countries, as pointed out by Belbase and Grabowski (1985). Determining farmers' technical efficiency at the farm level can play a crucial role in natural resource management and increasing the value of water. Effective water resource management requires optimizing water use efficiency across different sectors. Efficient irrigation systems and water-saving technologies contribute to reducing water demand and minimizing environmental impacts. Enhancing WUE in water-stressed regions can alleviate the pressure on freshwater resources and promote sustainable water allocation (Sharma et al., 2015).

Tunisia has prioritized the development of its irrigated agricultural sector to ensure the country's food security. However, due to the growing scarcity of water resources, Tunisia has shifted its focus from supply management to demand management strategies. In 1995, the National Water Saving Program (NWSP) was established to promote efficient water use, with the primary

African Scientific Journal
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Vol : 3, Numéro 17 , Avril 2023

objective of rationalizing the use of agricultural water to maximize economic benefit and maintain irrigation water demand in line with water resource availability in the long term. Irrigated areas in Tunisia cover 465,000 hectares and consume approximately 2.14 billion m3 of water annually, of which 74% is groundwater (ITES, 2014). This excessive utilization has led to the overexploitation of many deep aquifers (Frija et al., 2014). The agricultural sector, being the largest consumer of water in Tunisia, faces challenges in effective management. State regulation is hindered by the large number of users, informal use practices, and limited resources of public organizations responsible for water management (Shah, 2014; Frija, 2014). Additionally, technical and allocative inefficiencies resulting from suboptimal water use at the farm level, market failures in irrigation equipment, difficulties in rehabilitating irrigated land, farmers' debts, and land property issues contribute to weak irrigation efficiency (Chebil and Frija, 2016).

The measurement of productive efficiency at the farm level is a crucial aspect for both researchers and policy-makers. Understanding the extent to which a farm can increase its output by enhancing its efficiency without utilizing additional resources, particularly scarce resources such as water, is imperative. In situations of water scarcity, it is essential to assess the level of technical efficiency (TE) and water use efficiency (WUE) at the farm level and to identify the sources of inefficiency to devise suitable policies for enhancing irrigation performance. Several studies have examined the assessment of TE and WUE in various regions of Tunisia, revealing that agricultural WUE remains low in the agricultural sector (Albouchi et al., 2007; Dhehibi et al., 2007; Frija et al. 2009, Mahdi et al., 2010; Chemak et al., 2010; Chemak and Dhehibi 2010; Chebil et al., 2012; 2013, Abdelhafidh et al., 2021). As a result, numerous aquifers are overexploited, and the national groundwater overexploitation rate stands at 20% (Besbes, 2018). The primary non-renewable water table is depleting and deepening, mainly because of overexploitation in irrigated areas and inefficient use of irrigation water.

Measuring WUE provides valuable information for evaluating the performance of water governance systems. It enables the assessment of how effectively water resources are managed, allocated, and utilized to meet societal needs. By quantifying the benefits derived from water use in relation to the quantity of water consumed or withdrawn, water use accounting help in identifying areas of inefficiency or wastage in water governance systems. This information can guide policymakers and water managers in making informed decisions (Wu et al., 2022) and thus improving the governance mechanisms to enhance resource efficiency. The present study on water use efficiency (WUE) is a component of a broader research into water governance in

Tunisian irrigated areas. The particular focus on WUE provides valuable insights into the efficiency and effectiveness of water use practices in arid Tunisia, offering a better understanding of water governance challenges. In this case study, water use and technical efficiencies measurements were used as a tool for performance assessment, stakeholder engagement and policy formulation within water governance framework in public irrigated areas in Tunisia. By regularly monitoring and assessing WUE, water governance systems can identify changing trends, evaluate the effectiveness of interventions, and adapt strategies accordingly.

Numerous studies have been conducted on measures to enhance Technical Efficiency (TE) and Water Use Efficiency (WUE). However, the novelty of this paper lies in several factors. Firstly, it provides an in-depth analysis of WUE in irrigated areas, taking into account the combination of factors that affect agricultural performance under policy reforms related to irrigation technology. Secondly, to the best of our knowledge, there has been no prior research conducted in our study area, which is a border region between Tunisia and Algeria. Finally, the previous research focused on monoculture farming systems, whereas our study deals with a multicultural farming system. This study aims to contribute in two ways: first, to measure TE and WUE at the farm level, and second, to analyze the multi-cropping farming system, as prior research has mainly focused on monocropping systems.

The remainder of this paper is structured as follows: Section 2 will detail the methodology used, section 3 will present the empirical results, and section 4 will provide concluding remarks.

1. Materials and methods

The aim of this study is to evaluate the technical efficiency (TE) and water use efficiency (WUE) of farms using the Data Envelopment Analysis (DEA) method. The DEA method is used to determine the TE of each farm while holding other inputs constant. Additionally, the constant return to scale (CRS) and variable return to scale (VRS) assumptions are compared to identify the production scale efficiency. The VRS specification is used to calculate TE without the scale efficiency (SE) effect (Coelli, 1996). The TE and WUE assessments are conducted using the General Algebraic Modeling System (GAMS) program. Furthermore, the study explores the influence of socio-economic and technical factors on the efficiencies using a Tobit model.

1.1.Technical and Water use efficiency calculations

In the agricultural sector, estimating the technical efficiency (TE) and water use efficiency (WUE) is a crucial instrument for evaluating resource allocation to improve management practices and adjust regulatory measures. The Farell measures of efficiency, inspired by Koopmans (1950), define efficiency as achieving maximum output while minimizing inputs or a combination of the two (Farell, 1957; Farell and Fieldhouse, 1962). At the farm level, TE can be achieved by using fewer inputs to produce a given output or reaching a higher level of outputs for a given amount of inputs used. Water productivity, as defined by Kijne et al. (2003), is a robust measure of a system's capacity to convert water into food. Agricultural water productivity is a basic expression of output per unit of water consumption, which can be measured for the entire system or parts of it, defined in time and space (Cook et al., 2006). Sub-vector efficiency measures such as WUE are induced by an increase in a subset of inputs while maintaining other inputs and outputs constant (Speelman et al., 2007).

The DEA method is a recognized tool for modelling operational processes and calculating efficiency scores at the farm level (Cooper et al., 2011). DEA is a non-parametric method for measuring the performance of decision-making units (DMUs) that transform multiple inputs into multiple outputs (Cvetkoska, 2011). The first work and discussions on DEA emerged with Dantzig (1951) and Farrel (1957). The CCR model was developed by Charmes, Cooper and Rhodes (1978) to measure the efficiency of DMUs, which is the basic research direction of efficiency calculation for production units in the field of operational research (Forsund and Sarafoglou, 2002).

African Scientific Journal
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Vol : 3, Numéro 17 , Avril 2023

DEA uses linear programming to estimate the efficient and performance frontier of a given number of DMUs (Zhu, 2014). The aim is to identify the DMU that displays the best performance. The efficiency score is defined as a number between 0-1 or a percentage between 0-100%. The TE concept suggests that the problem is technical and deals with the techniques of a specific input called management (Leibenstein, 1977). Farell (1957) identified two technical efficiency metrics: the input-oriented measure, which scales the inputs of inefficient units with a common scalar, projecting the point radially to the frontier while maintaining the observed output constant, and the output-oriented measure, which scales the outputs of inefficient units with a common scalar, projecting the point radially to the frontier while maintaining the observed inputs constant.

The current paper applies a non-parametric Data Envelopment Analysis (DEA) methodology with the Variable Returns to Scale (VRS) assumption to determine the Total Efficiency (TE) and the water sub-vector efficiency of irrigated agricultural farms. The DEA approach is widely used in the agricultural sector to evaluate the performance of farms in terms of technical efficiency (TE) and allocative efficiency (AE). The CCR model (Charnes et al., 1978), which is an input-oriented model that considers Constant Returns to Scale (CRS), is used to measure the efficiency of the sample farms. This model determines the efficient production frontier or envelopment surface, and the farm efficiency measure is determined by the radial distance towards this frontier (Paço and Pérez, 2013).

Banker et al. (1984) expanded the CCR model to the BCC model to account for the Variable Scale Return (VRS) condition. The ratio of the CRS and VRS efficiency scores provides the average scale efficiency (Coelli et al., 2002). Scale Efficiency (SE) represents the average productivity level that a farm can achieve while operating at the optimum scale (Farell, 1957; Taib et al., 2018).

The VRS assumption is preferred for the current study since it considers the short-term view and the unit size is assumed to be established (Metters et al., 1999; Paço and Pérez, 2013). In the case of irrigated agricultural farms, the VRS hypothesis is appropriate because an increase in the volume of irrigation water does not necessarily lead to an increase in crop yield (Rodrìguez Dìaz et al., 2004). Therefore, the VRS assumption is more appropriate for evaluating the technical efficiency and water sub-vector efficiency of irrigated agricultural farms in this study.

The DEA-BCC model had been adapted to measure TE. Considering K farms (DMUs), each farm employ N input X_{nk}(n=1,..., N), to generate M outputs Y_{mk}(m=1,...,M). Each DMU_0

becomes the reference unit, θ refers to its efficiency and α_k is a vector of k elements corresponding to the effect of each DMU in determining the DMU_0 efficiency. The pure technical efficiency is measured by solving the model below:

$\mathrm{Min}_{\theta,\alpha}\theta$

s.t.$\sum_{k=1}^{K} \alpha_k \, Y_{m,k} \geq Y_{m,0}$

$\sum_{k=1}^{K} \alpha_k \, X_{n,k} \leq \theta . X_{n,0}$

$\sum_{k=1}^{K} \alpha_k = 1$

$\alpha_k \geq 0$

WUE, subset input, is measured by adapting a sub-vector efficiency notion. Technical sub-vector efficiency, WUE is determined based on Färe et al. (1994) previous work. The Irrigation water sub-vector TE can be measured by solving the following model:

$Min_{\theta^t,\alpha}\theta^t$

s.t.$\sum_{k=1}^{K} \alpha_k \, Y_{m,k} \geq Y_{m,0}$

$\sum_{k=1}^{K} \alpha_k \, X_{n-t,k} \leq X_{n,0}$

$\sum_{k=1}^{K} \alpha_k \, X_{t,k} \leq \theta^t . X_{t,0}$

$\sum_{k=1}^{K} \alpha_k = 1$

$\alpha_k \geq 0$

Where θ^t, which takes a value ranging from 0 to 1, presents the maximum decrease of the input t, holding outputs and residual inputs (n-t) constant. We denote that the constraint $\sum_{k=1}^{K} \alpha_k = 1$ has been added to consider the return to scale assumption.

Resources are considered as "inputs" and outcomes as "outputs". The outputs should depict all valuable outcomes on which we intend to analyse the DMUs. Moreover, any environmental factors that affect resource transformation into outcomes should also be embodied in the inputs or outputs regardless of the context of that effect (Thanassoulis, 2001).

1.2.Tobit model

In this study, the determinants of TE and WUE were investigated using censored regression. The use of limited dependent variable models, also known as censored or truncated regression, was pioneered by Tobin (1958). The Tobit model is a specific type of censored regression model that examines the relationship between a continuous dependent variable Y, which is subject to censoring or truncation, and a vector of independent variables Xi. Given that the dependent variable in this study varies between 0 and 1, the Tobit model is deemed appropriate. The Tobit model has been widely utilized in the analysis of the determinants of WUE in prior research (Speelman et al., 2007; Frija et al., 2009; Tipi et al., 2009; Chebil et al., 2013; Njiraini et al., 2013; Wang, 2010; Wang et al., 2018; Abdelahafidh et al., 2021). Amore (2019) defines the Tobit model as follows:

$$y_i^* = \beta x_i + \varepsilon_i \text{, with } \varepsilon \sim N(0;\sigma^2) \text{, and } y_i = \begin{cases} y_i^* if\, 0 \prec y_i^* \prec 1; \\ 0 if\ y_i^* \prec 0; \\ 1 if\ y_i^* \succ 1 \end{cases}$$

where y*: latent variable, x is a vector of independent variables supposed to influence efficiency, β are parameters associated with the independent variables to be estimated and y: observed depended variable.

Since the dependent variable of efficiency varies between 0 and 1, Ordinary Least Square (OLS) leads to biased and inconsistent parameters estimation (Wooldridge, 2002). Therefore, the maximum likelihood estimation is a better choice to estimate the Tobit model.

1.3.Study area and data collection

The study area is located in the Central West of Tunisia, specifically in Kasserine governorate, which is known for its contribution to 5% of the national agricultural production and its prominence in arboriculture. Agriculture is the mainstay of the governorate's local economy, providing employment to a significant proportion of the population. To collect data on the agricultural practices of the region, we conducted surveys among 91 small-scale farmers in the Foussena area. The total irrigated agriculture area in Foussena is approximately 9343 hectares, with groundwater serving as the primary source of irrigation. Arboriculture is the dominant crop type, occupying nearly 3858 hectares, followed by cereals/field crops, vegetable cultivations, and fodder crops.

In such areas, farmers share a common resource according to a collectively organized scheme, and public irrigated areas cover 717 hectares serving 363 farmers. The intensification rate in the region is about 72%, while the exploitation rate is 68%, indicating a high level of agricultural activity. Moreover, about 57% of the farmers use water-saving equipment to

African Scientific Journal
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Vol : 3, Numéro 17 , Avril 2023

optimize irrigation practices. Fruit and olive trees constitute 47% of the total cultivated land, indicating the importance of these crops in the region's agriculture.

Groundwater in the deep aquifers of Foussena (Plioquaternary of Foussana, Foussena Sandstone) is extracted from 789 boreholes at a rate of 4.5 Mm3/year, which represents an exploitation rate of about 355%. Our research is based on field investigations that took place between March and June 2017-2018, during the agricultural campaign. A stratified random sampling approach was adopted, and the sample comprised 25% of the total farmers who used groundwater in public irrigated areas. To estimate the water use efficiency (WUE) scores, we collected variables that are detailed in Table 1. Furthermore, Table 2 provides a summary of the statistics of the independent variables used in the Tobit regression analysis.

Table .1 Descriptive statistics of the variables used in efficiency measures

	Mean	**Standard deviation**	**Minimum**	**Maximum**
Output (10^3TND*)	16.045	37.744	0.363	353.12
Water (10^3TND)	1.294	0.897	0.066	4.493
Cultivated land (10^3ha)	0.0024	0.0016	0.2	0.011
Labor (10^3TND)	0.554	0.413	0.05	2.4 1
Fertilizers (10^3TND)	1.959	5.825	0	5.826
Seeds (value)	2.084	3.124	0	24.662
Mechanization (10^3TND)	1.096	1.153	0	5.813
Manure (10^3TND)	0.723	2.595	0	2.4
Trimming 10^3 (TND)	0.262	0.406	0	2.4
Other costs (10^3TND)	0.398	2.643	0	25
Phytosanitary treatment (10^3TND)	0.688	1.509 10^3	0	10.5 10^3

*Tunisian National Dinar TND (1TND =0.35 USD in 2021)

Source: Data collected by the authors during the study

African Scientific Journal
ISSN : 2658-9311
Vol : 3, Numéro 17 , Avril 2023

Table .2 Summary statistics for variables included in the Tobit regressions

	Variable description	**Variables continue**				**Variables dummy**	
		Mean	**SD**	**Min**	**Max**	**N° of farmers with dummy = 0**	**N° of farmers with dummy = 1**
Seniority	Years of experience in farming	26.26	14.08	2	69		
Water price	The price of cubic meter of irrigation water (TND)	.12	.037	.083	.277		
Irrigation water turns	The number of irrigation water turns per week	1.21	.53	0.3	3		
Tree farming	Area of irrigated tree framing (hectars)	.90	1.31	0	11		
Cereals	Area of irrigated cereals (hectars)	.63	1.09	0	4		
Forage crops	Area of irrigated forage crops (hectars)	.77	1.07	0	4		
Vegetable cultivation	Area of irrigated vegetables cultivation (hectars)	.14	.47	0	3		
Family mutual aid	Number of family workers on the agricultural holding	2.2	1.92	0	5		
Education	0= illetrate 1= primary education and higher					12	79
Access to credit	Whether to receive credit or not 0= No, 1=yes					71	20
Flood irrigation	Wether to use flood irrigation or not 0= No, 1=yes					63	28
Drip irrigation	Wether to use drip irrigation or not 0= No, 1=yes					49	42

Source: Data collected by the authors during the study

2. Results and discussion

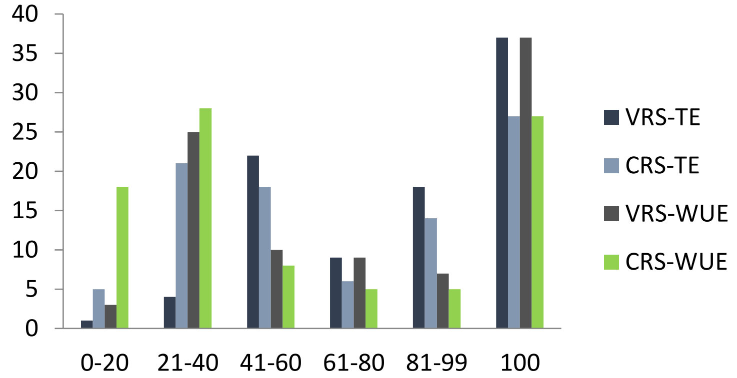
2.1.Sample characteristics

On average, the surveyed farmers cultivate an area of approximately 2.45 hectares, with 39% cultivating less than 2 hectares. Groundwater is the primary source of irrigation for all interviewed farmers, with nearly half utilizing water-saving equipment, while 31% continue to use flood irrigation. A majority of farmers, specifically 79%, have achieved an educational level surpassing primary education, and 65% have more than 20 years of agricultural experience. The majority of the sample, 78%, do not have access to credit. Tree farming predominates the cultivated land, with 67% of the farmers practicing tree farming and only 13% cultivating vegetables. The price of a cubic meter of water varies from 0.083 TND to 0.277 TND, with the irrigation water turn varying across different areas: weekly, biweekly, thrice weekly, every two weeks, and once every three weeks.

2.2.Efficiency scores measurements

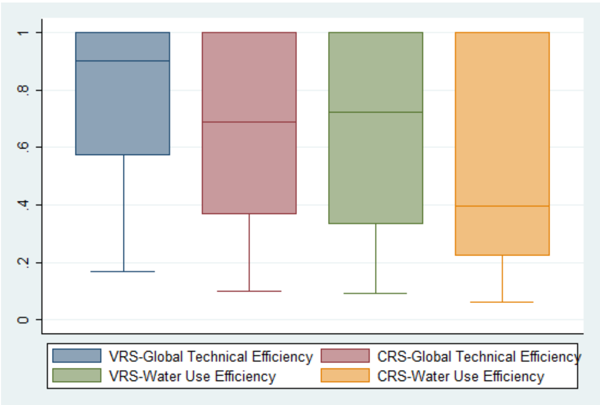
The results of the study highlight significant heterogeneity in performance between farms in terms of both water use efficiency (WUE) and technical efficiency (TE). The average WUE scores were found to be 54% and 68% under CRS and VRS assumptions, respectively, suggesting that farmers can achieve the same level of output with 32% less water by exploiting the equivalent amount of other inputs, under VRS. This emphasizes the importance of using water more effectively to save a large volume of water. The sub-vector water efficiencies reveal that there is room for improvement in terms of real inefficiency, indicating the need to identify and address the causes of inefficiencies. The frequency distribution of TE and WUE in Figure 1 shows that only 40% of farms are practicing irrigation efficiently (WUE score = 1) and that there is an average scale efficiency of 79%. This suggests that many farms are not operating at an efficient scale, and that an adjustment in the scale of operation could enhance efficiency. The average TE scores were found to be 66% and 79% under CRS and VRS assumptions, respectively, indicating that farmers can maintain the same level of production while using only 79% of the inputs under VRS. The results also suggest a 17% scale inefficiency following the difference between efficiency measures under CRS and VRS assumptions, revealing that improving this inefficiency could lead to an improvement in TE at the farm level. Additionally, Figure X.1 shows that most farmers have WUE scores under 65% and almost all of them have TE scores under 85% under VRS, highlighting the need for improvements in both WUE and TE in the agriculture sector.

Fig.1 Frequency distribution of technical and water efficiencies under VRS and CRS specifications



Source: Data collected by the authors during the study

Fig.2 Density distribution of water efficiency under CRS and VRS specifications



Source: Data collected by the authors during the study

African Scientific Journal
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Table.3 Scores of water sub-vector efficiencies under constant and variable return to scale specifications

Efficiency classes (%)	Technical Efficiency (% of farms)		WUE (% of farms)	
	CRS	VRS	CRS	VRS
Average efficiency	66	79	54	68
Efficiency min	10	17	6	9
Scale efficiency	83		79	

Source: Data collected by the authors during the study

2.3. Water use efficiency determinants

Table 4 displays the maximum likelihood estimation outcome for Tobit regression using STATA 15 software. The likelihood ratio (LR[1]) of the WUE Tobit model exhibits a statistically significant value of 34.62 at a significance level of 1%. The majority of the independent variables display a significant impact on WUE. Specifically, irrigation water turn exhibits a negative coefficient that is statistically significant at 1%. Moreover, the variable seniority reveals a negative coefficient of 10%. The variables for vegetable cultivation, cereals, and forage crops exhibit negative coefficients that are statistically significant at the 10%, 5%, and 1% levels, respectively. The utilization of surface irrigation exhibits a negative correlation with WUE, as indicated by the negatively correlated variable flood irrigation at a significance level of 5%. The current study highlights that family mutual aid in terms of irrigation at the farm level displays a positive relationship with WUE, exhibiting a positive coefficient at the 5% significance level.

[1] LR=-2(L_r-L_{ur}) where L_r is restricted log likelihood function and L_{ur} is unrestricted log likelihood function

African Scientific Journal
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Vol : 3, Numéro 17 , Avril 2023

Table 4. Results of the factors affecting the WUE scores (Tobit model)

	WUE	
	Coefficient	p-value
Const	0.974	0.000***
Education level	-0.096	0.292
Irrigation water turn	0.152	0.008***
Irrigation tech 1 (Drip)	-0.114	0.130
Seniority	-0.004	0.084*
Crop choice 1 (Tree farming)	0.005	0.851
Crop choice 2 (Vegetable cultivation)	-0.116	0.095*
Irrigation tech 2 (Flood irrigation)	-0.161	0.032**
Crop choice 3 (Cereals)	-0.075	0.014**
Crop choice 4 (Forage crops)	-0.084	0.006***
Family mutual aid	0.037	0.031**
Water price	-1.140	0.172
Access to credit	0.039	0.626
Number of observations	91	
Log-likelihood	-8.060	
Likelihood ratio (LR)	34.62***	

*Significant at 10%, **significant at 5%, ***significant at 1%

Source: Data collected by the authors during the study

3. Discussion

Water saving strategies have been implemented with the aim of enhancing agricultural water management and optimizing irrigation system performance. Studies on agricultural water management in Tunisia have shown that water use efficiency (WUE) remains below expectations, even with the use of water-saving technologies subsidized by the government.

The findings of this study are consistent with previous studies on the technical efficiency (TE) and WUE at the farm level in Tunisia (Albouchi et al., 2007; Frija et al., 2009; Chebil et al., 2013; Hanafi et al., 2015). This study also found that WUE scores were lower than TE scores under both constant returns to scale (CRS) and variable returns to scale (VRS) assumptions. While no significant interaction was found between the use of drip irrigation and WUE, a statistically significant relationship was found between surface irrigation (flood irrigation) and WUE at the farm level. However, caution should be exercised in interpreting this result, as the misuse of water-saving irrigation technology could be a possible explanation for this finding. The study also revealed that knowledge of basic irrigation parameters, such as irrigation dose and distribution network characteristics, is essential for optimal management of irrigation networks. Farmers surveyed reported high pressure variations in irrigation networks and a lack of flow limiters, which are essential for a pressurized distribution network to avoid variations in water inflow. The shift from furrow irrigation to water-saving irrigation methods did not necessarily result in improved TE and WUE (Hanafi et al., 2015). Inadequate transfer of technology, poor quality of equipment, and irregular water supply are also potential explanations for the inefficiencies observed in irrigation water use. The study found that irrigation water turns significantly affect WUE, possibly due to common pool externality consequences that can lead to inefficient use or overuse of resources. The unreliable water supply and technical weakness of the management of operations of water distribution agencies are major reasons for farmer disappointment with the water service. Demand-based irrigation scheduling can be an effective mechanism for enhancing WUE, and family mutual aid concerning irrigation practices can also significantly affect the effective use of irrigation water. The inverse relationship between WUE and planting cereals and forage crops was also observed, as these crops are irrigated through wasteful gravity irrigation. The cubic meter price of irrigation water was found to be statistically insignificant for both WUE and TE under VRS assumption, despite exhibiting variability. Access to credit and external financial resources was also found to be not significant but consistently positively related to WUE. In conclusion, this study provides important insights into the factors that affect TE and WUE at the farm level in Tunisia, highlighting the need for effective water management strategies that consider factors such as irrigation practices, equipment quality, and access to financial resources.

Conclusion

The objective of this study is to evaluate the technical and irrigation water use efficiencies at the farm level in irrigated areas of the Tunisian arid region. The study utilized data envelopment analysis and Tobit regression methods to analyze data obtained from a sample of 92 farms. The findings of the investigation indicate that, on average, water use efficiency is 68% under the variable return to scale assumption. This suggests that farms can maintain their output by reducing irrigation water use by 32% while keeping other inputs constant. The Tobit regression analysis highlights that reducing the practice of flood irrigation, irrigation water turns, family mutual assistance among farmers, and selecting more suitable crops have a positive impact on water use efficiency levels. Therefore, promoting small-scale family farming, enhancing irrigation water turn, and adapting cropping systems to local conditions are recommended to improve the efficiency of the irrigated agriculture sector. Despite the exploratory nature of this study, it offers valuable insight into the performance of public irrigated areas in the arid region, particularly under conditions of water scarcity and institutional management problems. The implications of these findings are significant for agrarian reforms and agricultural extension policies. Nonetheless, it is noteworthy that this study solely examines the efficiency of public irrigated areas managed by Water Users' Associations. Future research could extend these findings by evaluating water use efficiency in private irrigated areas, where farmers invest in boreholes and extract water directly from water tables.

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