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Analysis of water saving investment of agricultural sector in Tunisia

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Abstract

This study aims to evaluate the performance of the National Program for Water Economy in Irrigation (NPWEI), which has been implemented in Tunisia since 1995, and to assess the impact of water-saving investments on agricultural water productivity. To achieve these objectives, two approaches were adopted. First, descriptive analysis was used to estimate the differences in water consumption, crop yields, and gross margins between traditional and modern irrigation systems. Second, an econometric model was used to assess the impact of investments in water-saving technologies on water productivity.
Drip irrigation systems were found to lower the average water consumption of the crops studied by approximately 5.200 cubic meters per hectare annually. In addition, agricultural yields increased significantly by 30% in arboriculture and about 60% in vegetable and cereal crops. The productivity gains resulted in an average additional gross margin of nearly 2.000 TND/ ha, across various crops.
Econometric analysis shows that water-saving investments have a positive impact on water productivity that is statistically significant at the 5% level.
Based on these findings, several policy recommendations are proposed. These include enhancing farmer training and extension services, improving access to high-quality irrigation equipment, and adjusting financial support mechanisms such as microcredit and subsidies to better benefit smallholder farmers and young rural entrepreneurs. Finally, strengthening institutional coordination between water users' associations and agricultural development actors is essential to promote sustainable use of water resources.

1. INTRODUCTION

In the face of increasing demand, the water shortage in the Mediterranean is a major challenge. In fact, for most Mediterranean countries including Tunisia, water is a limiting factor in their economic and social development. Despite 40 years of considerable efforts to mobilize the country's water resources, Tunisia is facing water scarcity. The available water per capita is about 410 m3/year in 2014 which is lower than 500 m3 (considered to be the annual minimum required to meet the needs of each) (FAO, 2021; IPCC, 2014).

Agriculture in Tunisia is considered to be the major water-intensive sector. It is estimated at 75 % of total water abstraction (FAO, 2021; MARHP, 2019; World Bank, 2018).

The total irrigated area covered by the program reached approximately 424,700 ha in 2023. This includes 95,800 ha under improved gravity irrigation, 114,700 ha under sprinkler irrigation, and 241,000 ha under drip irrigation. The surface under drip irrigation has increased in recent years, following the implementation of the National Program for Water Economy in Irrigation (NPWEI). Overall, the program has significantly expanded the area equipped with modern irrigation systems from 9851 ha in 1995 to 241,000 hectares in 2023 (ONAGRI, 2023).

To the best of our knowledge, there is a noticeable gap in the literature regarding comprehensive evaluations of national-scale water-saving initiatives in agriculture, particularly within the Tunisian context. Most existing studies have focused either on localized case studies or on the technical performance of irrigation systems without systematically assessing their economic or environmental outcomes. In light of this, the present study seeks to address this gap by providing an impact analysis of the National Program for Water Economy in Irrigation (NPWEI).

This paper is structured as follows: Section 2 provides an overview of the NPWEI, outlining its objectives, implementation framework, and key developments. Section 3 describes the methodology employed for data collection, analysis, and evaluation. Section 4 presents the results and discussion, highlighting the program's outcomes, challenges, and impacts on water use efficiency in the agricultural sector. Finally, Section 5 offers the conclusions and policy recommendations, based on the findings, with the aim of informing future strategies for sustainable water management in Tunisia.

2. OVERVIEW OF NATIONAL PROGRAM FOR WATER ECONOMY IN IRRIGATION

The Tunisian government launched NPWEI in 1995 which is based on three interdependent components: i) conservation of water resources (reduction of technical losses and leaks, etc.) ii) financial and Technical Incentives and iii) institutional Strengthening (decentralization by incentive the creation of WUAs) (Hamdane, 2021; Treyer, 2002).

The program includes a subsidy rates for modern irrigation equipment—covering 40%, 50%, and 60% of investment costs for large, medium, and small farms, respectively. Between 1995 and 2023, total investments under the NPWEI amounted to approximately 1692 million dinars (MD), of which 768 MD were financial incentives from the State. As a result, the adoption of water-saving technologies (WST) has markedly improved. In fact, the percentage of irrigated land equipped with such technologies rose from 37% in 1995 to 96% in 2023 (National Water Sector Report –2023).

The three strategies of the NPWEI are as follows: institutional reforms, water pricing, and subsidies for WST.

2.1 Institutional reforms

Tunisia implemented significant institutional and regulatory reforms to enhance the governance and efficiency of its irrigation water management, establishing a new framework focused on decentralization, cost recovery, and sustainability through various decrees and presidential decisions.

The dissolution of the OMIVA (Offices for Agricultural Development) in 1990, which had managed irrigated areas as public entities, was a major turning point. Their responsibilities were then assigned to the Regional Commissariats for Agricultural Development (CRDAs), public administrative entities functioning under the Ministry of Agriculture. This institutional shift marked a transition from centralized to regionally managed water governance, aiming to enhance responsiveness to local conditions and improve administrative efficiency.

In 1987, the Tunisian government enacted Decrees No. 87-1261 and 87-1262, which formally established the legal framework for WUAs (Frija et al, 2015). A key component of this reform has been the transfer of responsibilities from the CRDAs to WUAs. This shift reflects a broader strategy to promote participatory and demand-driven governance in the water sector, with the goal of improving the efficiency, equity, and sustainability of irrigation systems (World Bank, 2018; El Abed, 2020). WUAs, composed primarily of local farmers, are tasked with operating and maintaining irrigation infrastructure, setting user fees, and ensuring equitable water distribution.

By 1995, the government had implemented additional measures to stimulate the adoption of WST and practices. These included financial incentives and investment subsidies, aimed at reducing water losses, increasing crop productivity, and promoting the diffusion of modern irrigation techniques such as drip irrigation. Collectively, these reforms represent a foundational phase in Tunisia's efforts to modernize its irrigation infrastructure and promote more sustainable water resource management in the face of increasing scarcity.

2.2 Water pricing

The management of irrigation water demand has centered on replacing traditional gravity irrigation with "modern" methods, such as localized irrigation (drip) and sprinkler systems. Additionally, increasing irrigation water prices was viewed as another tool for managing demand. Between 1990 and 2003, irrigation water tariffs rose by 400%, which left farmers with little option but to adopt drip irrigation, despite its high cost and relatively short lifespan (Thabet & Chebil, 2006).

Furthermore, the increase in irrigation water prices directly impacts the profit margins of small farms, which are already limited. Once a certain threshold is surpassed, the high cost of irrigation water tends to encourage illegal water tapping and diminishes the recovery rate of water charges. It is important to note that the average price of irrigation water is estimated at 0.110 DT/m^3, with the actual price ranging from 0.028 TND/m^3 (in southern oases) to 0.175 TND/m^3 (for large farms in the north). Overall, the cost of water remains a significant part of total crop expenses, averaging around 14-15%, except for cereals, where it can reach up to 20%, despite the tariff advantages provided for these crops (Thabet et al, 2024).

These two measures, water pricing and modern irrigation methods, primarily affect efficiency at the plot level but do not influence the efficiency of irrigation water supply and distribution networks. Improving the latter requires periodic assessments of irrigated areas, strengthening network monitoring, enhancing preventive maintenance, conducting leak detection campaigns, and providing technical oversight of agricultural development groups, among other actions.

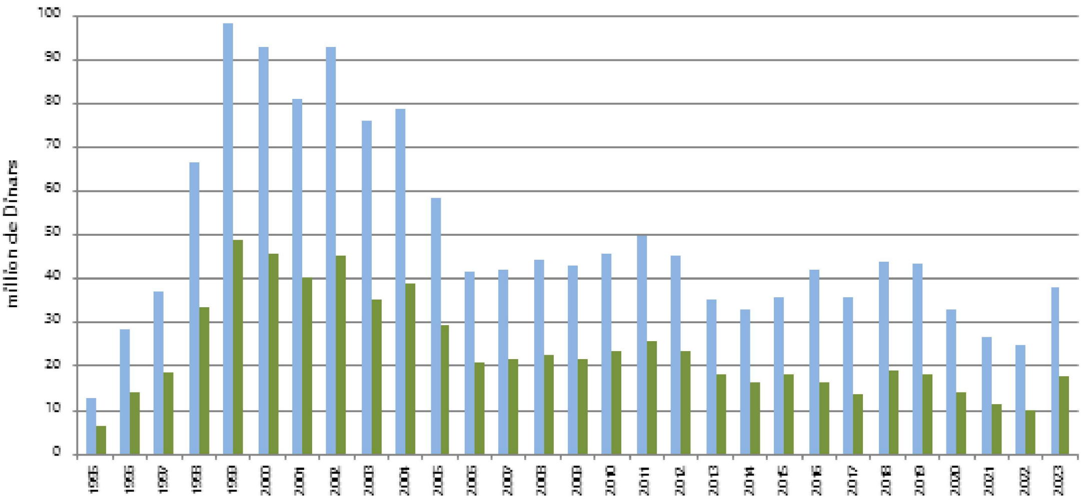
Water pricing mechanisms have been designed to support specific objectives such as cost recovery and agricultural intensification. Strengthening the capacity of WUAs is also a crucial aspect of sustainable water management, allowing them to take greater responsibility in resource management and infrastructure maintenance. To facilitate this transition, Provisional Management Committees have been created to provide training, assist in restoration projects, and contribute to the establishment of new irrigation perimeters. These committees are expected to evolve into collective interest groups (GICs), fostering a more decentralized and participatory approach to water governance.

2.3 Subsidies

In 1995, the Tunisian Water Authority launched the NPWEI whose main objectives are: the rational use of water in all areas, mainly the irrigation water system, ensuring better economic development of the latter and maintaining appropriate levels of water demand are considered insufficient to ensure the sustainability of resources. The implementation of the program should make it possible to achieve an overall efficiency in the irrigated agriculture sector of close to 85% at the distributional level. To achieve this, huge amounts of equipment have been deployed. The investment in these projects is estimated at 1692 MD, including subsidies of 768 MD (ONAGRI, 2023). Investment from medium and large farmers (B and C categories) accounted for 64% of the total investment, while small farmers (A category) received only 36% of the total (DGGREE, 2002).

3. METHODOLOGY

The methodological approach adopted in this study combines quantitative performance indicator analysis (difference between program beneficiaries and non-beneficiaries) with



Total Investment : 1692 MD Subsidies : 768 MD

Fig. 1. Trends in Total Investments and Subsidies Allocated Under the NPWEI (1995-2023)

econometric modeling, to assess the impact of Tunisia's water-saving investment policies on water productivity.

3.1 Performance Indicators

To provide a comprehensive evaluation, several key performance indicators were selected. These indicators measure the technical and economic efficiency of irrigation water use, and enable comparison between areas with and without participation in water-saving programs. The selected indicators include:

- **Water Physical Productivity (WPP):** Defined as the volume of agricultural output per cubic meter of irrigation water used (kg/m^3), this indicator reflects technical efficiency.
- **Share of Water Cost in Total Production Cost (SWC):** This represents the proportion of water-related expenses within the overall production costs, serving as a proxy for input efficiency.
- **Water Economic Value (WV):** This indicator estimates the monetary value derived per unit of irrigation water (TND/m^3), indicating how effectively water contributes to value creation.
- **Gross Margin (GM):** The difference between total revenue and variable costs (TND/ha), used to assess farm profitability under different irrigation systems.

3.2 Econometric Model Specification

To complement the descriptive analysis, an **econometric model** is specified to assess the impact of water-saving investments on water productivity. The model is defined as follows:

$$Y = f(\mathrm{IN, EX, D}) \quad (1)$$

Where:

- Y is the dependent variable representing **water productivity**, which is proxied by the **value added per hectare (TND/ha)**.
- IN is the **real water-saving investment** (in TND).
- EX denotes **real public agricultural extension expenditures** (in TND).
- D is a **dummy variable** capturing drought years, where D=1 if drought year (Standardized Precipitation Index (SPI) is less than -1), and D=0 otherwise.

Considering that the life span of water saving equipment is about 7years, we calculate this variable as moving average taking into considering the depreciation amount in each year.

Equation (1) could be expressed in log form in the following way:

$$\log(y) = \alpha 0 + \alpha 1 \log(IN) + \alpha 2 \log(EX) + \alpha 3D + \varepsilon \quad (2)$$

Where :

- log (Y) is the logarithm of **water productivity**, proxied by **value added per hectare** (TND/ha);
- log (IN) is the logarithm of the **real water saving investment**;
- log (EX) is the logarithm of **real public agricultural extension expenditures**;
- D is a **dummy variable** indicating drought conditions, where D=1if the **Standardized Precipitation Index (SPI)** is less than -1, and D=0 otherwise;
- ε is the **error term**, assumed to be normally distributed.

3.3 Data sources

The used data are collected from several sources:

- Real value added per ha variable is obtained from the yearly statistical data reports of the Ministry of Agricultural, Hydraulic Resources and Fisheries (nominal VA) and Central bank (PI).

- Real amount of water saving investment is constructed from yearly statistical data reports of the Ministry of Agricultural, Hydraulic Resources and Fisheries (nominal amount of investment) and Central Bank (PI)

- Standardized Precipitation Index (SPI) is calculated from precipitation data of National Institute of Meteorology (INM), as follow:

$$SPI = \sigma P - \mu \quad (3)$$

Where:

- P = **observed precipitation** (for the month or period)
- μ = **mean precipitation** (historical average for the same period)
- σ = **standard deviation** of historical precipitation

The Standardized Precipitation Index (SPI) is a widely used tool to quantify drought conditions. In econometric analyses, a dummy variable for drought can be defined, taking the value of 1 when SPI is less than 0 (indicating below-average precipitation) and 0 otherwise

- Real public agricultural extension expenditures variable is calculated from yearly statistical data reports of the Ministry of Agricultural, Hydraulic Resources and Fisheries (nominal public agricultural extension expenditures) and Central bank (price index).

4. RESULTS AND DISCUSSION

4.1 Trend of key performance indicators of Program

4.1.1. Equipped areas with WST

WST are the dominant irrigation method in Tunisia, covering nearly 425,000 hectares, which is 96.5% of the total 442,000 hectares of irrigated land in 2023. These WST areas include 95,800 ha with improved gravity systems, 114,700 ha under spraying, and 241,000 ha utilizing drip irrigation (Fig. 2).

By the end of 2025, and depending on water availability, Tunisia's national water strategy aims to enable irrigation for roughly 460,000 hectares of both public and private areas.

4.1.2 Profitability of NPWEI

The NPWEI's evaluation revealed a significant rise in farmers' incomes, with water savings generating incremental benefits ranging from 64% to 76% in tree planting and a more substantial 53% to 160% in commercial gardening. These investments showed promising returns, often within two and a half years.

For farmers who used to practice gravity irrigation, the goal of water saving was first to reduce water bills and facilitate manual irrigation work. The sharp increase in production and income exceeded their expectations (Water Sector Study: Ministry of Agriculture /BECHTEL/ SCET Tunisia, 1998). The results were much better than expected.

According to the Water Sector Study (Ministry of Agriculture /BECHTEL/ SCET Tunisia, 1998), the subsidy for local irrigation is 0.214 TND per cubic meter of water, and the dose is 5000 m^3/ha (vegetable cultivation, arboriculture). Similarly, for irrigation by sprinkling, the subsidy is 0.279 TND/m^3 for 2000 m^3/ha of cereals and winter fodder, and 0.111 TND for 5000 m^3/ha of summer fodder.

According to Table 1, all examined economic indicators for the studied crops were improved with the implementation of NPWEI compared to scenarios without it. Furthermore, the proportion of water expenses relative to total expenses was lower under NPWEI.

4.2 Estimation results of the econometric model

To estimate the econometric model specified in equation (2), the Ordinary Least Squares (OLS) method was initially applied. However, the Durbin-Watson (DW) statistic indicated the

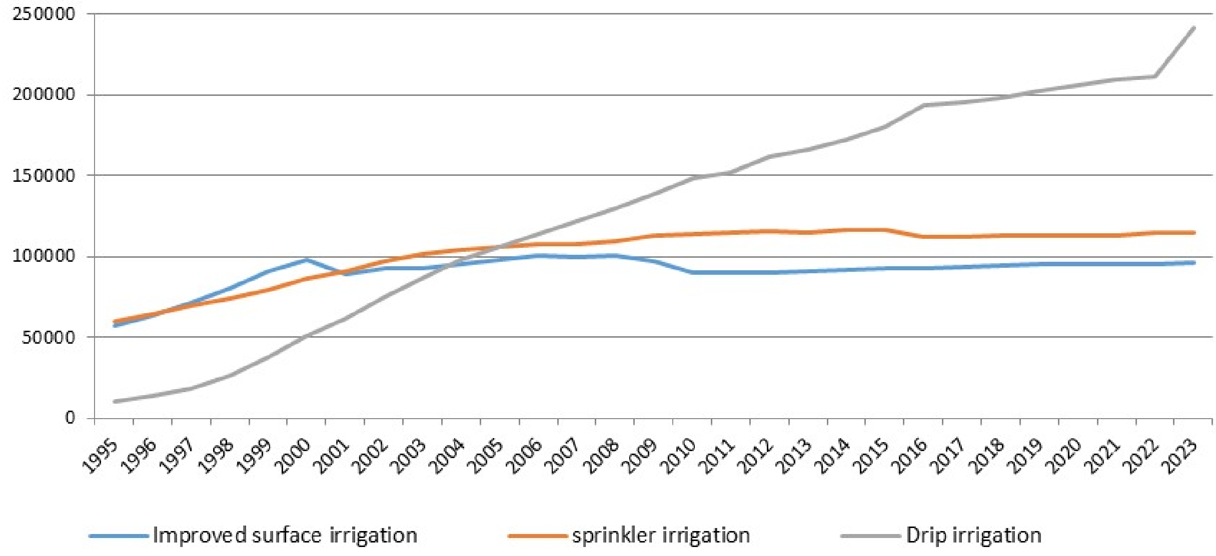


Fig. 2. Evolution of equipped surfaces with WST (1995-2023)

Table 1. Evolution of the financial performance of crops with and without the NPWEI

Weighted average	Water value (TND/m³)	Water expenses/total expenses	Physical water production (kg/m³)	Gross Margin (1000 TND/ha)
		Wheat		
With NPWEI	0.58	19.8%	1.756	1.108
Without NPWEI	0.204	25%	1.073	0.515
		Forage		
With NPWEI	1.793	13.9%	10.841	4.132
Without NPWEI	1.103	16.6%	5.155	0.780
		Vegetable farming		
With NPWEI	0.985	14.1%	5.622	6.040
Without NPWEI	0.665	15.3%	3.439	2.433
		Arboriculture		
With NPWEI	1.063	14.7%	1.950	4.753
Without NPWEI	0.380	25.4%	0.880	2.603

Source: DGREE, 2015

presence of serial correlation in the residuals, which violates the OLS assumption of independently distributed errors.

To correct for this issue, an autoregressive model of order two (AR (2)) was adopted, assuming that the disturbance term follows a second-order autoregressive process. This adjustment significantly improved the model's fit and eliminated the problem of autocorrelation.

The results of the corrected estimation, referred to as model (2), are summarized in Table 2. The model demonstrates a strong explanatory power, with an adjusted R-squared (R^2) of 0.81, indicating that 81% of the variation in water productivity is explained by the model. The t-statistics reveal that all estimated coefficients are statistically significant at the 5% level, with the exception of the intercept. Furthermore, the test for residual autocorrelation confirms the absence of serial correlation after correction, thus validating the robustness of the estimates.

Table 2. Regression Results

Variables	Coefficient	t-value
Constant	0.215	0.65
DR	-0.107	-2.40**
INV	0.298	3.34**
EX	0.769	2.06*
AR (1)	0.539	2.65**
AR(2)	0.406	1.73*
$\overline{R}^2 = 0.81$	**F(5,19)=21,91****	**DW=1.99**

***Significant at the 5% level, * significant at the 10% level*

As expected, the coefficient associated with the drought dummy variable (D) is negative and statistically significant, indicating that drought episodes have a detrimental effect on water productivity. On the other hand, the estimated coefficients for water-saving investment (IN) and public extension services (EX) are both positive and statistically significant at the 5% level. This finding supports the hypothesis that increased financial support for efficient irrigation technologies, combined with effective agricultural extension services, contributes positively to enhancing water productivity at the farm level.

4.3 Discussion

Drought significantly impacts irrigation water productivity in agriculture, both globally and in Tunisia. In fact, a study in Spain (Peña-Gallardo et al, 2019) assessed the effects of drought on rainfed crops. The research found that drought indices calculated at different timescales, including the SPI, closely correlated with crop yield. Several studies also suggested that different patterns of yield response to drought occurred depending on the region, period of the year, and the drought timescale (Qiao et al, 2024; Abobatta, 2019).

In Tunisia, droughts have led to significant reductions in water availability for irrigation, adversely affecting agricultural productivity.

Econometric models incorporating SPI-based drought indicators have been utilized to assess these impacts. For instance, a study of Terwayet Bayouli et al, 2023 analyzing the relationship between drought conditions and crop yields in Tunisia found that droughts, as indicated by negative SPI values, were associated with substantial decreases in yields of key crops such as wheat and barley. The results of this study are consistent with our findings, which emphasized the value of the SPI as a valuable tool for tracking the effects of drought on agriculture in this area. (Ben Abdelmmalek & Nouiri, 2020; Chebil et al, 2019; El Kharraz et al, 2012; Gargouri et al, 2010).

In addition, our results show that extension services affects positively and statistically significant at the 5% level the water productivity. These results are online with several studies conducted by researchers which provided strong empirical evidence of the positive effects of expenditures on agricultural extension services on productivity growth in Tunisia (Dhehibi et al, 2014; Chebil et al, 2015; Frija, et al, 2015).

The integration of WST was one important initiative that has evolved water productivity in Tunisia. The installation of drip irrigation systems, for example, has been associated with increased crop productivity. According to the study conducted by Messaoudi et al, (2024), drip-irrigated crops realized water use efficiencies of about 90% compared to about 50% under surface irrigation. Several studies conducted in Tunisia revealed that the adoption of WST can considerably promote the water use efficiency (Ben Ammar et al, 2023; Chebil et al, 2012).

A detailed examination of drip irrigation's effects in China indicated a significant enhancement in WP, showing an increase from 6.74% to 7.93% when compared to traditional irrigation methods (Yang et al, 2023).

In conclusion, investing in WST is a key strategy for improving WP in Tunisia. This strategy has led to a general increase in agricultural yields, with increases ranging from 30% in tree crops to over 60% in market gardening and cereals. The economic value of irrigation water has doubled across all crops, reaching an average of 1 TND/m^3 of water in tree crops, and up to 2 TND/m^3 for some crops such as table grapes, apple trees, peach trees, and almond trees (Messaoudi et al, 2024). These analyses, in concordance with our results, highlighted the importance of tailored strategies to promote the adoption of WST, thereby enhancing WP and contributing to sustainable water management.

5. CONCLUSION AND RECOMMENDATIONS

The research study evaluates the benefits generated from the adoption of the National Program for Water Economy in Irrigation (NPWEI) in Tunisia with special reference to water saving technologies. There is a remarkable reduction in water use, and there is also increased agricultural production.

The results of econometric model show that the investments in water-saving technologies for NPWEI do significantly enhance performance in the water productivity of the agricultural sector. In general, these results demonstrate the effectiveness of NPWEI in the adoption of more sustainable irrigation practices through the agricultural sector which has proven the increase of the areas under this type of the irrigation in the last decades in Tunisia.

Based on this analysis, several policies need to be implemented such as better training of farmers, enhanced access to irrigation technology, and revision of financial aid policies like microcredit which is more inclusive of smallholder and young farmers. Greater collaboration between water user associations and agricultural development agencies is also recommended towards better support of farmers to access and use this technology.

This incentive policy of drip irrigation also needed to be investigated at the national level by comparing total public cost for the subsidy of this program and compare it to the total benefit generated from irrigated areas in Tunisia. This will add more relevance and evidence towards greater support of the government financially to this technology.

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