Farm-level and aggregate socio-economic impacts of adopting innovative irrigation management: A Tunisian case study.

Hacib El Amami, Ali Chebil, Abdelaziz Zaïri, Rim Zitouna, Insaf Mekki.

[1] INRGREF, Carthage University, Tunisia

hacib.amami@gmail.com

Abstract.

Groundwater has transformed Tunisian rural economies through improved crop productivity and diversification, rising incomes of groundwater farmers as well as agricultural laborers. However, in a virtually absence of effective regulation, the large scale adoption of irrigation has led to enormous extraction rates of groundwater, often exceeding natural recharge rates. The severe depletion of many aquifers cannot wholly sustain the production that has been initiated. In this context, the optimization of irrigation amounts and frequency to match water application to the water needs of the crop require scientific irrigation scheduling practices. Innovative (smart) irrigation management, developed within SUPROMED project, is viewed as a subset of practices that contribute to increase crops yields and decrease costs while contributing to saving water and improving energy use. The aim of this paper was to analyze the socio-economic impact of such management at the farm and at regional/national levels. At the farm level the methodology consists of comparing impact before and after Supromed practices on treated farmers, and comparing these changes with those observed in the control group. The regional/national aggregated socio-economic impact is derived from the advantage of innovative management observed at the farm level multiplied by the number of individual farmers adopting such practices. Results showed that smart management allowed better water and energy efficiency as well as higher yields, compared to conventional management. The gross margin per ha and per cubic meter were also higher. For all monitored crops, the obtained indicators are above the average indicators observed at the regional and national level. Based on the adoption rate of 80%, the water saved would represent 8-9% of the national quantity used in agriculture while contributing to increasing production by at least 26%. By developing irrigation scheduling models, combining calibrated crops local data (Kc and phonological stages), local weather conditions and rainfall forecasts to provide end-users a Decision Support System, this study suggests that there is a substantial opportunity to improve the agronomic and economic efficiency of water and energy use in arid regions.

Keywords: smart technologies, innovative, water, management, energy, productivity.

1 Introduction

In the central and southern parts of Tunisia, where surface water is both scarce and random, groundwater is the only source of irrigation. Over the last 40 years, favorable marketing opportunities for various crops and the easy and heavily subsidized availability of water lifting technology launched in these regions have led to a real intensive groundwater withdraft, tapping reserves which could not be reached with older technologies. Current estimates show that 100,000 wells were installed and about 50 percent of the agricultural area (430,000 ha) is being irrigated by surface wells. Groundwater has transformed rural economies through improved crop productivity and rising incomes of groundwater farmers as well as agricultural laborers. It can be considered as an example of success of agricultural policies in these regions.

However, such rapid growth is not without serious environmental implications since it has introduced the challenge of groundwater sustainability as this resource is falling quickly at a rate of 1-2 m per year (Hemdi, 2022). In this context, the use of water for agricultural production requires innovative and sustainable strategies to increase its efficiency as well as crops productivity. Conventional irrigation systems apply irrigation water without considering the spatio-temporal variation of soil characteristics and changes in weather variables that affect crop evapotranspiration (Vories et al., 2021). The majority of farmers rely on calendar based methods and/or the visual symptoms for irrigation. This usually result in either under irrigation or over irrigation and both of them can cause significant yield losses. Over irrigation may lead to excessive vegetative growth and fewer photosynthates for the growing flowers, and thus lower the yield potential while inadequate irrigation may lead to plant stress that may result in a reduction in crop yield and quality. Smart-irrigation systems are widely suggested as a valuable approach to increase crops yields and decrease costs while contributing to saving water and improving energy use by scheduling the amount of irrigation according to soil characteristics, crop types and weather conditions (Kamiensky et al, 2019).

It is a key in ensuring higher water use efficiency as it enables farmers to save precious resources without subjecting plants to moisture deficiency. Smart irrigation involves the application of water at the right time, in the right amounts, and at the right spot in the field (Singh et al., 2019).

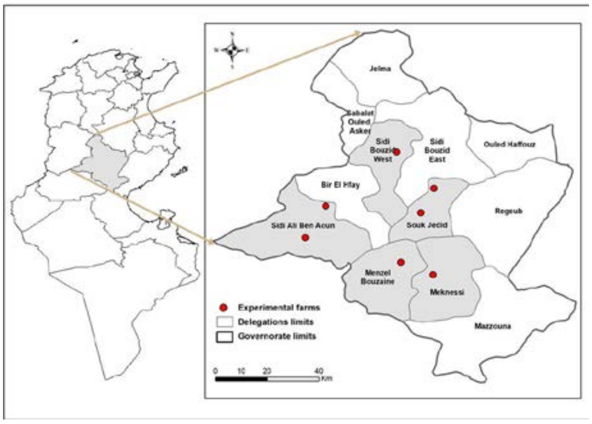
The SUPROMED project (Sustainable Production in water limited environments of Mediterranean Agro-Ecosystem) was implemented a smart water management system in this region. It’s implying the employment at the level a sample of farmers several in-field sensors such as a water level sensor, temperature sensor, water pressure sensors and field weather stations. The monitored crops were: wheat, oat, olive, pistachios and almond trees. The irrigation for the selected crops was scheduled by MOPECO model based on data gathered by the soil humidity sensors, crops’ phonological stages and local weather station.

We hypothesized that innovative irrigation management based on local data (soil, GDD, local weather conditions etc.) combined with best agricultural practices could not only increase water productivity but also improve grain yield and social benefits by contributing to growers’ net profit and reducing water application and energy use as well as production cost. The overall objective of this study was to analyze the economic and environmental impact resulting in utilizing smart irrigation management at the farm and national level. The expected goals would contribute to the extension of innovative irrigation management, and increasing resilience of agro-ecosystems to water scarcity.

2. Methodology

2.1 Study area

The geographic setting for this analysis is Sidi-Bouzid located in the central parts of Tunisia (Fig.1). Strongly governed by the arid climate, the average annual rainfall calculated during the period (1936-2012) was approximately 180 mm and characterized by significant annual fluctuations with a coefficient of variation ranging from 25% to 80%. About 56% of precipitation occurs between September and April. The average annual evaporation is 1470 mm per year and the ratio of evaporation to rainfall for the area is 7.5. Therefore, agriculture is primarily based on intensive irrigation, since rainfall hardly meets 30 to 35 per cent of the water requirements even for winter crops. Due to the aridity of the climate, the area has little surface water and groundwater is the only source of water irrigation.



The region of Sidi Bouzid is one of the main centers of agricultural production in Tunisia, especially for vegetable crops (18% of national production), fruit trees (13% of almond production 10% of olive oil) and milk production (PREDD, 2014).

2.2. Analytical approach

Within SUPROMED project we have selected two sample of farms situated in the same areas with similar environmental conditions. In the first sample, the irrigation for the monitored crops (wheat, oat, olive, pistachios and almond trees) are scheduled by MOPECO model based on data gathered by the soil humidity sensors and local weather station. For the second, the farmers were left to perform the type of water management usually practiced in the area. All data relative to the various agricultural practices, inputs used as well as obtained yields and market prices/costs were recorded from the first preparation of soil to the harvesting. The quantity of water applied is based on measurements at the field.

Several indicators were used to assess the farm and aggregate level economic and environmental impact of using SUPROMED irrigation management recommendation. They include economic and environmental indicators. Economic indicators cover gross margin (GM), total production cost (TC) and the share of water in total production cost. Gross margin was used as a proxy for profitability of an enterprise. Gross margin is defined as the difference between gross value of production and total variable costs. The Gross value is estimated as the prevailing market price of a given output multiplied by quantity of output sold. Total variable costs is a summation of all input variable costs incurred by a given producer. The economic water use efficiency is also calculated. It's defined as the benefit of a unit of water to its users and is established as the relationship between gross margins and the total water applied with respect to single crops. With these values, it is possible to obtain an economical-ecological relationship for a single crop depending not only on monetary benefits but also on the water consumption needed to achieve those benefits. All impacts were calculated on a per-hectare and per-year basis. Environmental indicators include energy and water saving. The ratio of energy expenses per monetary unit of output was also calculated.

These indicators were calculated, in a first step, at the farm level. The aggregated economic impact of the project is derived from the total number of individual farmers adopting such practice. It is estimated by weighting the indicators per unit (ha) obtained at the level farm by the number of units willing to adopt the innovative practices. To estimate the number of adopting units we have conduct a survey over a sample of 96 farmers affected by the project. The adoption rate is calculated by simply computing the percentage of the adopters from the sample. In this study, it indicates the maximum proportion of the target population that will possibly adopt the innovative irrigation management.

3. Results

Results were reported both at the farm level and national level.

3.1. Impact at the farm level

3.1.1. Agronomic indicators: Water use and yields

For annual crops (onion, wheat, oat), the best results are for SUPROMED treatments. They obtained the best values of yield than those observed for farmer's control plots. Table 1 shows that the total volume of water applied under SUPROMED recommendations was less as compared to water applied by the control group of farmers for the same crops, except for pistachios trees where the water delivered by farmers is lower. But, the corresponding yield is also lower. This is mainly due to that pistachios trees in the study area are usually conducted under rainfed or deficit irrigation.

Table 1: Yields and water use for selected crops under two form of irrigation management: innovative and conventional form (Sup Supromed ; Farm : Farmers).

Crops	Unit	Onion		Wheat		Oat		Almond		Pistachios	
		Sup.	Farm.	Sup.	Farm.	Sup.	Farm.	Sup.	Farm	Sup.	Farm.
Yield	T/ha	81	49	64	43	10.08	6.7	1,4	1,8	0.8	0.35
Water	m^3/ha	7320	9235	4100	6120	3470	3370	5550	9670	2200	2135
Water productivity	Kg/m^3	11.1	5.3	1.56	0.72	2.9	1.2	0.252	0.186	0.364	0.162

The average water applied by control farmers group for almond trees is much higher than that applied on Supromed plot. They obtained a higher average yield, however the water productivity, denoting the amount of product over volume of water diverted, is much lower than that obtained on the experimental plot.

These results reveal that innovative irrigation management based on local data (soil characteristics, GDD, local phonological stages of crops and local weather conditions) combined with best agricultural practices could not only increase water productivity but also save water and improve grain yields.

3.1.2. Energy indicators

Table 2 shows the energy indicators (energy productivity and specific energy) for monitored crops under innovative (SUPROMED) and conventional irrigation management. The term energy productivity used in this study denotes the ratio between yields, expressed in terms of Kg, and the energy input, expressed in terms of Kwh. As it was seen from the table 2, the maximum energy productivity was obtained on the plots managed under the Project recommendations compared to conventional management.

Table 2: Energy productivity relative to each form of irrigation management.

Crops	Unit	Onion		Wheat		Oat		Almond		Pistachios	
		Sup.	Farm.	Sup.	Farm.	Sup.	Farm.	Sup.	Farm	Sup.	Farm.
Energy productivity	kg/Kw	41.3	19.6	5.78	2.6	10.7	7.4	0.49	0.36	0.71	0.319
Specific energy	Kwh/Kg	0,024	0,05	0,173	0,573	0,093	0,135	2	2.74	1,4	3.15

Specific energy shows the amount of energy spent to produce one unit of marketable product (kWh/kg). It was much lower for experimental (Supromed) plots than for others, meaning that control farmers have used more energy to produce one kg of each product. As an example, the average's farmers adopting conventional management have used 3.5 times more energy than that used on Supromed plot to produce the same quantity of wheat (one kg). Therefore, it can be concluded that, for all crops, innovative irrigation management is more efficient in terms of both energy and water use.

3.1.3. Economic indicators

A comparison is made between "smart" and "conventional" irrigation management in terms of economic indicators. The gross margin (G.M) was calculated as gross income (yield multiplied by price) minus the variable cost of production. Here, gross margin was calculated both on per hectare and per cubic meter basis. As shown by Table 3, gross margin per ha and per m3 were better for plots conducted under the recommendations of the project based on local real data.

Table 3: Economic indicators of crops relative to each form of irrigation management.

Crops	Unit	Onion		Wheat		Oat		Almond		Pistachios	
		Sup.	Farm.	Sup.	Farm.	Sup.	Farm.	Sup.	Farm	Sup.	Farm.
Production cost	TND/ha	9100	7925	2723	2671	2355	1967	6806	6598	3514	1424
Irrigation cost share	%	13	18	18	30	20	23	19	46	22	41
Gross margin	TND/ha	11578	5569	5350	2202	3942	2223	5373	4998	12499	7000
Economic Water efficiency	TND/m^3	1.581	0.603	1.3	0.36	1.15	0.67	0.969	0.518	5.68	3.27

*1DT ≈ 0.37 USD

The share of irrigation cost in total production cost is also lower, meaning that the adoption of innovative irrigation management not only increases water productivity and improves yields but also decreases the cost of production. As a consequence, farmer's income will significantly increase.

3.2. Aggregate impact at national level

3.2.1. High adoption rate

The surveys carried out on the sample of 96 farmers involved in the project showed that more than 80% of them showed a particular interest in using the new irrigation practices and Decision Support Systems in order to improve irrigation management, increase yields and reduce the irrigation cost. This coefficient (80%) was used as the adoption rate when we calculate the aggregate impact of the project at the national level.

3.2.1. Production increase

As it was seen from Table 4, the yield generated by experimental plots is higher than the national average yield for all crops.

Table 4: The potential to increase production at the national level.

Crops	Supromed Yield (T/ha)	National average yield (T/ha)	Potential to increase yield relative to Supromed (%)
Wheat	6.5	3.5	86
Oat	10.1	9	12
Onion	82	30	173
Almond	1.4	1.35	3.7
Pistachios	0.8	0.35	129
Olive	6.3	3.5	80

Results revealed that there is substantial potential to increase production at the national level via improve irrigation management at the farm level combined with good agricultural practices. The potential of increase ranges from 12% for oat crop to 129% for pistachios trees.

3.2.2. Water saving

The table 5 shows, for each type of selected crop, the quantity of water that can be saved at the national level, when farmers adopt the innovative irrigation management.

Table 5: Estimation of water saving at the national level

Crops	Supromed treatment (m^3/ha)	Average National water use (m^3/ha)	Water saving (m^3/ha)	National average irrigated area (ha)	Water saving at national level (m^3)
Wheat	3600	4300	700	48100	33670000
Oat	3474	4200	726	17166	12462516
Onion	7320	9231	1911	15196	29039556
Almond	5550	8250	2700	11640	31428000
Pistachios	2200	5000	2800	3230	9044000
Olive	3960	5500	1540	115820	178362800

This quantity is close to 180 million m^3, representing thus 8-9% of the total volume of water used in irrigated agriculture, which varies depending on the year between 1900 and 2100 million m^3.

3.2.3. Energy saving

Table 5 shows that the specific energy to produce a marketable product (Kwh/kg) observed at the level of experimental plots is lower than that observed at the national (average). The resulting energy saving is substantial.

Table 5: Energy saved at the national level (Kwh: Kilowatt-hour, GwH: Gigawatt-Hour).

Crops	Specific energy to produce a marketable product (Kwh/kg)		Energy saved Kwh/kg	Average national production (kg)	National energy saved per crop (10^3Kwh)
	Experimental plots	Average national level			
Wheat	0,17	0,4	0,23	168350	38721
Oat	0,09	0,15	0,06	154494	720
Onion	0,02	0,1	0,08	455880	36470
Almond	1,9	1,95	0,05	15714	786
Pistachios	1,04	4,57	3,53	1130,5	3991
Olive	0,32	0,55	0,23	405370	93235

From this table, it can be drawn that the amount of energy that can save at the national level is more than 170 Gwh, representing this 26% of the total electric energy used in agriculture in Tunisia.

3.2.4. Saving cost and increasing income

In water-scarce areas, the cost of irrigation represents the major component of the variable cost. Thus, this high share of the irrigation cost indicates that any reduction in the volume applied to crops could have a considerable impact on the profitability of irrigated crops and on farmers' income. Table 6 shows that the production cost on experimental plots is lower than the average production cost observed at the national level, leading thus to a significant reduction in production cost for each crop.

Table 6: Average production cost at national level and on experimental plots.

Crops	Average Production cost at national level (TND/ha)	Average production cost on experimental plots (TND/ha)	Reduction cost relative to Supromed plots (%)
Wheat	3014,4	2873,6	-5%
Oat	1942,4	1795,2	-8%
Onion	8329,6	7942,4	-5%
Almond	7235,2	6684,8	-8%
Pistachios	5961,6	5392	-11%
Olive	3516,8	3104	-13%

Innovative water management and precision agricultural in general, provide an opportunity to reduce the production costs by optimizing the volume of water applied while increasing benefits through improved yields.

5. Conclusion

This study aimed to identify the potential impact at farm and national level resulting from adopting innovative irrigation management on increasing yields and water productivity as well as energy saving and improving farmer's incomes. Results showed that smart management allowed better water and energy efficiency as well as higher yields, comparative to conventional management. The gross margin per ha and per cubic meter were also higher. Results showed also that under smart management farmers' incomes become more resilient towards market prices variability leading thus to better economic viability of the farms. All indicators obtained on experimental plots (farm level) are higher than those observed at the regional and national level, meaning that there is opportunity to better increase yields with less water while increasing benefits farmers in limited environmental water.

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