

## THE TECHNICAL EFFICIENCY OF COLLECTIVE IRRIGATION SCHEMES IN SOUTH-EASTERN OF TUNISIA

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### ABSTRACT

*The purpose of this paper is to assess the technical efficiency (TE) and proposes a measure for irrigation water efficiency (IE) based on the concept of input-specific technical efficiency for a sample of 46 irrigators in Zeuss-Koutine region (South eastern Tunisia). In this paper, data envelopment analysis (DEA) is used to quantify TE and IE. A major finding of the study is that the irrigation systems are clearly inefficient. Under constants returns to scale (CRS) specification, the average technical efficiency of the sample was 71.75%. A similar pattern of scores was shown for IE; although in this case the average IE was even lower (49.9%) indicating that if farmers became more efficient using the technology currently available, the same level of output can be produced using the same level of other inputs but with, on average, 50.1% less water irrigation. In a second stage, critical determinants of sub-vector efficiency are determined using a Tobit model. Education level (EDU) and agricultural training (AGT) showed a significant impact on the subvector efficiency for water. Such information is valuable for extension services and policy makers since it can help guide policies towards increased efficiency.*

**Keywords:** Irrigation, Technical efficiency, DEA method, Irrigation water efficiency, Tobit model, South-Eastern of Tunisia.

### 1. INTRODUCTION

Irrigation water is becoming an increasingly scarce resource for agriculture in many regions of the world. A common ground in past policy schemes was the development of adequate irrigation infrastructure the supply of irrigation water as the demand for agricultural products was increasing. However, these expansionary policies have led to a massive use of irrigation water at a heavily subsidized cost, and a scarcity of the resource. Water shortage has become an increasing social and economic concern for policy makers and for those who must compete for the resources. In particular, policy makers are beginning to point to agriculture as the sector at the core of the water problem. Tunisian water reserves are estimated at 4.7 billion m<sup>3</sup>/year, of which 2.7 billion m<sup>3</sup> comes from annual rivers in the north, 0.7 billion m<sup>3</sup> from groundwater in the centre, the plains and the coastal area, and approximately 1.3 billion m<sup>3</sup> from the deep groundwater table mainly in the south (Al Atiri, 2007). Water resources are unevenly distributed across the country, with around 60% located in the north, 18% in the centre and 22% in the south. Water resources that have a salinity of less than 1.5 g/liter are distributed as follows: 72% of surface water resources, 8% of shallow groundwater and 20% of deep groundwater (Hamza, 2008).

Taking into account the limited water resources and the frequent disparity between supply and demand during dry seasons, Tunisia has engaged over the last three decades in a dynamic program of water mobilization. Several investment projects have been granted, reaching 9% of total investments in the government's Development Plan X (2002-2006), in which it has invested 19% in water programs. Agriculture, which accounts for approximately 12% of the GDP, is the sector that consumes the most water 80% of the available water resources ([Ministry of Agriculture, 2010a](#)).

Today, the irrigated areas reached 450 thousand hectares (8% of useful agricultural land) of which 240 thousand hectares were arranged in irrigated public areas. In such areas, farmers share a common resource according to a collectively organized scheme. The rest, called irrigated private areas, use surface wells as private resources. Irrigated agriculture consumes 80% of the available water resources and represents 35% of the output value derived from the agricultural sector, 22% of exports, and 26% of agricultural employment. Irrigated areas provide 95% of horticultural crops and 30% of dairy production ([Frija et al., 2009](#)). Moreover, the efficiency of the irrigation networks is relatively weak, estimated at approximately 50% ([Bachta and Gherzi, 2004](#)). Therefore, during the recent decades concerns regarding the efficient use of water resources in the country have increased.

Over the past two decades the government has implemented different programs in order to improve the irrigation water use efficiency (IWUE) and to enhance the overall performance of the sector. In fact, since 1990 a new tariff policy has been put into place. Each year the price of water has been increased by 15% in nominal value (9% in real value) in order to improve managing cost recovery and to encourage farmers to minimize water wasting. Also, since 1990 the management of collective irrigation schemes has been transferred to the users through the creation of water user associations (WUAs), which have the responsibility for selling and managing the distribution of water. Also, in 1995, the government launched The "National program of water conservation" which aims to minimize the losses of water at field level. This program allows farms that introduce water saving irrigation systems (sprinklers, drip irrigation) to get up to 60% of the investment subsidized. Today, the number of WUAs has risen strongly from about 100 in 1993 to 1250 in 2009 managing around 188 000 hectares of irrigated lands ([Ministry of Agriculture, 2010b](#)). They were responsible for the management of 42.4% of the irrigated land in Tunisia. However, despite such a development, significant difficulties remain in collective irrigation system ([Elloumi and Gara, 1993](#)) and irrigation water use efficiency (IWUE) remains the most important issue for the Tunisian irrigated sector ([Chemak et al., 2010](#)).

In this context, the objective of this paper is to estimate and assess the technical efficiency (TE) and irrigation water efficiency (IE) in collective irrigation schemes using Data Envelopment Analysis (DEA) for a randomly selected sample of 46 farms operating in seven collective irrigated perimeters located in Zeuss-Koutine region (South-eastern of Tunisia). This choice of the study area is motivated by the expansion of irrigated agriculture ([Romagny et al., 2004](#)), by the few

studies about IWUE that have been done in this region (Mahdhi *et al.*, 2011) and by the overpumping of deep groundwater (Yahyaoui, 2010).

## 2. METHODOLOGY

### 2.1. Efficiency Measures

Technical efficiency is defined as the ability of a farm to either produce the maximum possible output from a given bundle of inputs and a given a technology, or to produce the given level of output from the minimum amount of inputs for a give technology (Basanta *et al.*, 2004). The absolute efficiency position of farmers is usually not known. Therefore the problem is to measure the efficiency of one farm relative to others. The evaluation of farm specific technical efficiency is usually based upon deviations of observed output or input vectors from the best production or efficient production frontier. Farrell (1957) was the first to use frontier production functions to measure technical efficiency. Firms that are technically efficient will be located at the frontier, while those that are not will appear below the frontier, with the ratio of the actual to potential production defining the level of efficiency of the individual firm. In empirical work frontier production functions are obtained from available data, and technical efficiency estimates are based on empirical relations from sampled data, where the estimated efficiency scores in the current study indicate how much a farm should be able to minimize the use of all inputs in the production process, while continuing to produce the same level of output.

In the present analysis, we consider the inefficiency in the use of a single input, irrigation water, (for alternatives see, e.g. (Lilienfeld and Asmild, 2007; Speelman *et al.*, 2007; Frija *et al.*, 2009); Oude Lansink *et al.* (2002) ). This measure generate a “sub-vector efficiency” measure which only estimates the relative input reduction potentials in a subset of the inputs or individual input, in this case irrigation water alone, rather than the reduction potential in all inputs simultaneously. The efficiency measure produced can be called “irrigation water use efficiency” or in the case of irrigated production, “irrigation water efficiency” (IWUE).

Irrigation water efficiency, as previously defined in the literature (McGockin *et al.*, 1992; Omezzine and Zaibet, 1998) is given by the ratio of effective water use, i.e., the amount of water actually utilized by crop to the water applied to the crop.

Based on this definition, a sprinkler irrigation system could reduce water use and increase irrigation efficiency compared to a furrow system, but at the expense of an increase in capital. On the other hand, drip irrigation could be more efficient in water use than sprinklers depending on land characteristics. In purely engineering terms, it has been found that, for surface irrigation methods, average irrigation water efficiency is about 0.6, whereas drip or sprinkler technologies may increase efficiency up to 0.95 (Karagiannis *et al.*, 2003).

Irrigation water efficiency, as defined above, is a physical measure of a given irrigation technology, presuming a level of management, and thus it is not directly comparable to technical efficiency, as defined by Farrell (1957), which is a measure of management capability (Karagiannis *et al.*, 2003). However, as any other production technology, a sprinkler irrigation system for

example could possibly be technically inefficient in Farrell's sense due to insufficient training or know how. More importantly, with improper management, a sprinkler irrigation system might use as much water as a furrow system and thus be technically inefficient compared to the well-managed furrow system (McGockin *et al.*, 1992).

## 2.2. Data Envelopment Analysis

Data envelopment analysis (DEA) was developed by Charnes *et al.* (1978) based on M.J. Farrell's contribution to productive efficiency. The data envelopment analysis technique uses linear programming methods to construct a non-parametric frontier. The technique also identifies efficient production units, which belong to the frontier, and inefficient ones, which remain below it. The evaluation of farm (the decision-making unit) performance is usually based on economic efficiency, which is generally composed of two major components: technical efficiency and price or allocative efficiency (Farrell, 1957). Technical efficiency is defined as the ability of a farm to either produce the maximum possible output from a given bundle of inputs and a given technology, or to produce the given level of output from the minimum amount of inputs for a given technology. Technical efficiency can be decomposed into two components: pure technical efficiency and scale efficiency (Sharma *et al.*, 1999). When one separates the scale effect from the technical efficiency, the pure technical efficiency is obtained. Scale efficiency relates to the most efficient scale of operation in the sense of maximizing average productivity. A scale efficient farm has the same level of technical and pure technical efficiency. Allocative efficiency is defined as the ability of a farm to equate marginal value product and marginal cost.

In the present paper, we focus on technical efficiency measure with input-oriented DEA models because, in the context of increasing water scarcity, it is more relevant to consider potential decreases in water use than increases in output (Frija *et al.*, 2009).

Following the Banker *et al.* (1984) BCC-DEA model is presented here for the situation with  $J$  farms ( $j=1, \dots, n$ ), each producing  $M$  outputs  $y_{mj}$  ( $m=1, \dots, M$ ) by using  $K$  different inputs  $x_{kj}$  ( $k=1, \dots, K$ ), each farm becomes the reference unit. For the  $i$ -th firm we have vectors  $x_i$  ( $k \times 1$ ) and  $y_i$  ( $M \times 1$ ). For the entire data set, therefore, we have a  $K \times N$  inputs matrix  $X$  and  $M \times N$  output matrix  $Y$ .

The technical efficiency (TE) measure is obtained by solving the following DEA model (equation 1):

$$\begin{aligned}
 & \text{Min}_{\theta, \lambda} \theta \\
 & \text{s.t.} \quad \sum_{j=1}^n \lambda_j y_{m,j} \geq y_{m,i} \\
 & \quad \sum_{j=1}^n \lambda_j x_{k,j} \leq \theta \cdot x_{k,i} \\
 & \quad \sum_{j=1}^n \lambda_j = 1 \\
 & \quad \lambda_j \geq 0
 \end{aligned} \tag{1}$$

where  $\theta$  is a scalar and  $\lambda_j$  is a vector of  $n$  elements representing the influence of each farm in determining the technical efficiency of the farm under study (farm  $i$ ),  $x_{k,i}$  and  $y_{m,i}$  are, respectively, the input and the output vectors of the farm  $i$ . The estimated value of  $\theta$  is the efficiency scores for each of  $N$  farms. The estimated will satisfy restriction  $\theta \leq 1$  with a value  $\theta=1$  indicating a technically efficient farm. To derive a set of  $N$  technical efficiency scores, the problem needs to be solved  $N$  times, one for each farm.

It should also be noted that equation 1 has a variable returns to scale (VRS) specification which includes a convexity constraint ( $\sum_j \lambda_j = 1$ ). Without that constraint, equation (1), would have constant returns to scale specification (CRS). Using that specification, it is assumed that farms are operating at their optimal scale (Fraser and Cordina, 1999). In the case of agriculture, increased amounts of inputs do not proportionally increase the amount of outputs. For instance, when the amount of water to crops is increased, a linearly proportional increase in crop volume is not necessarily obtained, one reason why the variable return to scale option might be more suitable for our problem (Rodriguez Diaz *et al.*, 2004). Coelli *et al.* (2002) and Haji (2006) on the other hand found that for small farms like the ones considered in this study, little scale economies could be realised, hence both specifications will be modelled. In addition, a comparison of both scores is interesting because it provides information on scale efficiency (SE). Coelli *et al.* (2002) showed that the relation is as follows:

$$SE_i = \frac{\theta_i^{CRS}}{\theta_i^{VRS}} \tag{2}$$

where  $SE=1$  indicates scale efficiency or CRS and  $SE < 1$  indicates scale inefficiency.

Using the notion of sub-vector efficiency proposed by Färe *et al.* (1994) in Oude Lansink *et al.* (2002), technical sub-vector efficiency for variable input  $k$  (irrigation water) is calculated for each farm  $i$  by solving the following linear programming (LP) problem (3):

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<sup>1</sup> $\theta^{CRS}$  and  $\theta^{VRS}$  denote the TE index of the  $i$ th firm under constant returns to scale ( $TE_{CRS}$ ) and variable returns to scale ( $TE_{VRS}$ ) respectively

$$\begin{aligned}
 \theta^t &= \min_{\theta, \lambda} \theta \\
 \text{s.t.} & \\
 \sum_{j=1}^n \lambda_j y_{m,j} &\geq y_{m,i} \\
 \sum_{j=1}^n \lambda_j x_{k-t,j} &\leq x_{k-t,i} \\
 \sum_{j=1}^n \lambda_j x_{t,j} &\leq \theta^t x_{t,i} \\
 \sum_{j=1}^n \lambda_j &= 1 \\
 \lambda_j &\geq 0
 \end{aligned} \tag{3}$$

Where  $\theta^t$  is the irrigation water efficiency score.  $\theta$ , can have a value between 0 and 1 where a value of 1 indicates that the observation is a best performer located on the production frontier and has no reduction potential on irrigation water. Any value of  $\theta$  smaller than 1, however, indicates water use inefficiency, i.e., that excess irrigation water is being used.

Based upon linear programming techniques, DEA creates a “best practice” production frontier based on the irrigators that produced their level of crop output with the least amount of water. What is implied is that those who are able to produce their output levels using the least amount of water are better water manager. These farms then serve as benchmarks against which the water use inefficiency of all other irrigators, or amount of “excess water” used, can be measured. As an example, a  $\theta$  value of 0.8 means that the observation should be able to produce the same level of output using 80% of its current level of irrigation water when compared to its benchmark which is constructed from the best performers with similar characteristics. The excess water used can then be calculated as  $(1-\theta)x_1$  which in the previous example means that the excess is 20% of the current amount of irrigation water used.

### 2.3. Determining Factors Affecting Efficiency

Analysis of the effects of firm-specific factors on productive efficiency has generated considerable debate in frontier studies (Sharma *et al.*, 1999). Use of a second stage regression model to determine the farm specific attributes in explaining inefficiency is suggested in a number of studies (e.g., (Sharma *et al.*, 1999; Shafiq and Rehman, 2000; Wadud and White, 2000). An alternative to this approach is to incorporate farm specific attributes in the efficiency model directly (e.g.,(Battese *et al.*, 1989)); (Kumbhakar *et al.*, 1991; Battese and Coelli, 1995).

The present study employs the former approach and uses a model to analyze the role of farm specific attributes in explaining inefficiency of water uses in irrigated farms based on collective wells. To motivate our empirical model we assume

$$\theta^{k*} = \beta_0 + \beta_1 z_1 + \beta_2 z_2 + \dots + \beta_n z_n + \varepsilon = \beta Z + \varepsilon \tag{4}$$

Where  $\theta^{k*}$  is the DEA sub-vector efficiency index used as a dependent variable. Z is a vector of independent variables related to farm specific attributes,  $\beta$  is the unknown parameter vector

associated with the farm specific attributes, and  $\varepsilon$  is an independently distributed error term assumed to be normally distributed with zero mean and constant variance,  $\sigma^2$ . The dependent variable in the regression equation (4) cannot have a normal distribution. The efficiency parameters vary between 0-1, they are censored variables and thus a Tobit model needs to be used. The variables included in the Tobit model are discussed in the following section.

### 3. CASE STUDY AND DATA COLLECTION

We collected our data from small-scale collective irrigated farms in the region of Zeuss-Koutine, located in south-eastern area of Tunisia and within governorate of Médenine. In this region irrigation activity is recently introduced and water scarcity is an important issue (Romagny *et al.*, 2004). The groundwater resources are scarce and over exploited. This exploitation reaches 158% with annual renewable resource of 20.31 Mm<sup>3</sup> (Yahyaoui, 2010). However, major institutional innovations to manage groundwater are absent. Improvements in groundwater use efficiency are an essential element to mitigate water degradation.

Total irrigated agricultural area of the region is 2727 ha. Two subsystems can be distinguished: the subsystem of private irrigated farms is based on surface wells (1423 farms with 2300 ha). The subsystem of collective irrigation schemes is based on collective tube-wells (170 farms with 427 ha), and it is managed by water users' association "*Groupement de Développement Agricole (GDA)*". The agricultural production is based on vegetables and fruit trees. The main crops produced in the region are fruits (46%), vegetables (36%), and cereals (8%). Total agricultural production of this region contributes with nearly 8% to the total regional agricultural production and provides 26% of labour recruitment in agriculture (Regional Agricultural Development Commissions of Medenine (CRDA), 2009). However, despite such a development, significant difficulties remain in collective irrigated perimeters as well as in private irrigated perimeters. Certain collective irrigation channels have decayed resulting in significant water losses of up to 40% (Regional Agricultural Development Commissions of Medenine (CRDA), 2009). The use of the flood irrigation system is dominant, which leads to significant water losses. The proliferation of surface wells increases the overexploitation of the groundwater that is reflected in folding back and in increased salinity of water as well as soils.

The study was conducted in seven collective irrigated perimeters (CIP). Data on vegetable cultivation were drawn from 46 randomly selected farms operating in seven CIP. The sample of farms was taken from a specific region geographical region in Sidi Maklouf and Medenine Sud districts. These districts represent 85.5 % of the total irrigated land area in the governorate of Medenine and the water scarcity and the increasing pressure on these ground water resources calls for a more efficient.

**Table-1.** Distribution of collective irrigated farms surveyed by delegation and by land area

| Delegations      | collective farms |        |    |       |
|------------------|------------------|--------|----|-------|
|                  | ≤1ha             | 1-2 ha | >2 | Total |
| SidiMaklouf      | 08               | 06     | 10 | 24    |
| MédenineSud      | 07               | 06     | 09 | 22    |
| Total study area | 15               | 12     | 19 | 46    |

The selected sample comprises 15 farms smaller than one hectares (32.6% of the sample), 12 ranging between one and two hectares (26.1%) and 19 larger than two hectares (41.3%). It represent 27% (116 ha) of the total collective irrigated land area in Zeuss-Koutine region.

Questionnaires were collected during the 2008-09 harvesting period. During the interviews information was gathered on the irrigation schemes, household characteristics, farm activities, quantities and costs of inputs used in production, quantities and value of output, the quantity of water consumed and irrigation practices. In general this type of farmers does not keep records concerning their farming activities, so data gathered during interviews was based on recollections of farmers. The expert knowledge of the extension staff was used as a supplement to the recollections of the farmers, something that was particularly helpful for the estimation of the water use and the prices of their produce.

Vegetable farmers in the research are grow a wide range of vegetable crops, including tomatoes, cucumbers, peppers, potatoes, watermelons and green pepper. In addition, cereal and olive tree cover a reduced surface of the area study; they are not included in the analysis.

For the purpose of efficiency analysis, the dependent variable is the total annual vegetable production measured in Tunisian Dinar (TND). The aggregate inputs considered in the analysis are: (1) land measured in hectares; (2) irrigation water measured in m<sup>3</sup>; (3) total labor, comprising of hired (permanent and casual), family and contract labor, measured in working days; (4) Chemical inputs, including fertilizers (nitrogenous, phosphate, potash, complex and others), pesticides and insecticides measured in TND; (5) and others costs, comprising the rest of inputs used (mechanisation, etc). Summary statistics of these variables is given in Table 2.

**Table-2.** Descriptive statistics on outputs and inputs used in efficiency analysis.

| Variables       | Unit           | Mean | Max    | Min  | St.dev. |
|-----------------|----------------|------|--------|------|---------|
| Output          | TND            | 6340 | 25000  | 1000 | 5136.71 |
| <b>Inputs</b>   |                |      |        |      |         |
| Water           | m <sup>3</sup> | 7729 | 128304 | 800  | 5931.47 |
| Land            | Ha             | 2.52 | 20     | 0.25 | 2.91    |
| Labour man      | Days           | 708  | 1728   | 288  | 265.84  |
| Chemical inputs | TND            | 381  | 2700   | 115  | 443.84  |
| Others costs    | TDN            | 168  | 1000   | 16   | 164     |

**Note:** 1 TND (Tunisian Dinar) =0.50 Euros



In the Tobit analyses various farm-specific factors are analysed to assess their influence on the sub-vector efficiencies for water. The explanatory variables in the inefficiency effects include The share of family labour, farmer's age and its square, farmer's education, irrigated area equipped with water saving technologies and cultivated area (total area in ha).

To examine the role of relevant farm-specific factors in sub-vector efficiency the following equation is estimated:

$$\theta_i = \beta_0 + \beta_{1FA} + \beta_{2EDU} + \beta_{3AGT} + \beta_{4FSA} + \beta_{5FL} + \beta_{6FS} + \beta_{7EIA} + \varepsilon_i \quad (4)$$

where  $\theta_i$  is the DEA sub-vector efficiency index, FA is the farmer's age measured in years, EDU is education dummy variable (dummy = 1 if farmer accumulated at least 6 years of schooling, 0 otherwise), AGT is agricultural training dummy variable (dummy = 1 if the farmer has gone through agricultural training, 0 otherwise), FSA is the square of farmer's age measured in years, FL is the share of family labour, FS denotes the size of a farm defined in terms of the number of hectare, EIA is the irrigated area equipped with water saving technologies (drip and PVC irrigation technologies) and  $\varepsilon_i$  is random error.

## 4. RESULTS AND DISCUSSION

### 4.1. Technical and Irrigation Water Efficiency

The technical efficiency (Equation 1) is estimated using the program DEAP (Coelli, 1996) and irrigation water efficiency (Equation 3) were modelled in the General Algebraic Modelling System software (GAMS) using the methodology proposed by Speelman *et al.* (2007).

Average estimates of technical efficiency (TE) and irrigation water efficiency (IE) are presented in Table 3 in the form of frequency distribution within a decile range. The average overall technical efficiencies for the CRS and the VRS DEA approaches are 71.75% and 91.56% respectively, indicating that substantial inefficiencies occurred in farming operations of the sample farm households. Under the observed conditions, about 24% and 52% of farms were identified as fully technical efficient under the CRS and VRS specification respectively. Farms located in Sidi Maklouf region exhibited greater efficiency.

The first thing to note about these results is that under constant returns to scale (CRS), the efficiency score derived is either less or equal to the efficiency score derived for the variable returns to scale (VRS) specification for every farms. This reflects the fact that, under VRS, inefficient farms are only compared to efficient farms of a similar size. For this reason, more farms are efficient under the VRS formulation.

Under the VRS specification, the estimated input-oriented technical efficiency ranges from a minimum of 65.1% to 100% with an average estimate of 91.56%. This results means that a 8.44% decrease in all inputs is possible with present state of technology and unchanged outputs, or the same level of output can be reached by only using 91.56% of the used inputs, if technical inefficiency is completely removed. Thus, improving technical efficiency will significantly increase farm's revenue and profit.

The large differences between the CRS and VRS measures further indicated that many farmers did not operate at an efficient scale and that adjusting the scale of operation could improve the efficiency. The decomposition of the technical efficiency measure produced estimates of 8.44 percent pure technical efficiency inefficiency and 22 percent scale inefficiency. By eliminating scale inefficiency the farms can increase their average technical efficiency level from 71.75 to 91.56 per cent.

**Table-3.** Frequency distribution of efficiency scores for the studied farms sample

| Efficiency score (%) | Technical efficiency (TE) |            |    |             |            |    | Irrigation efficiency (IE) |            |             |            |
|----------------------|---------------------------|------------|----|-------------|------------|----|----------------------------|------------|-------------|------------|
|                      | CRS                       |            |    | VRS         |            |    | CRS                        |            | VRS         |            |
|                      | N° of farms               | % of farms | of | N° of farms | % of farms | of | N° of farms                | % of farms | N° of farms | % of farms |
| 0-10                 | 0                         | 0          |    | 0           | 0          |    | 8                          | 17         | 0           | 0          |
| 10-20                | 0                         | 0          |    | 0           | 0          |    | 5                          | 11         | 0           | 0          |
| 20-30                | 0                         |            |    | 0           | 0          |    | 6                          | 13         | 0           | 0          |
| 30-40                | 5                         | 11         |    | 0           | 0          |    | 5                          | 11         | 2           | 4          |
| 40-50                | 4                         | 9          |    | 0           | 0          |    | 1                          | 2          | 5           | 11         |
| 50-60                | 8                         | 17         |    | 0           |            |    | 3                          | 7          | 4           | 9          |
| 60-70                | 8                         | 17         |    | 2           | 4          |    | 2                          | 4          | 4           | 9          |
| 70-80                | 2                         | 4          |    | 7           | 15         |    | 3                          | 7          | 6           | 13         |
| 80-90                | 6                         | 13         |    | 10          | 22         |    | 1                          | 2          | 0           | 0          |
| 90-100               | 2                         | 4          |    | 3           | 7          |    | 1                          | 2          | 2           | 4          |
| 100                  | 11                        | 24         |    | 24          | 52         |    | 11                         | 24         | 23          | 50         |
| N                    | 46                        |            |    | 46          |            |    | 46                         |            | 46          |            |
| Mean                 | 71.75                     |            |    | 91.56       |            |    | 49.9                       |            | 65.6        |            |
| Minimum              | 34.5                      |            |    | 65.1        |            |    | 0.8                        |            | 30.2        |            |
| Maximum              | 1.00                      |            |    | 1.00        |            |    | 1.00                       |            | 1.00        |            |
| Sidi Maklouf         | 73                        |            |    | 96          |            |    | 70                         |            | 80          |            |
| Médenine Sud         | 68                        |            |    | 90          |            |    | 58                         |            | 67          |            |
| Scale Efficiency     | 78                        |            |    |             |            |    | 75.45                      |            |             |            |

Mean water efficiency is found to 49.9% and 65.6% under CRS and VRS, formulation, respectively, which is much lower than technical efficiency and also exhibits greater variability, ranging from 0.8% to 100% (see table 3). Under VRS assumption, the estimated irrigation water efficiency implies that the farms should be able to produce the same level of output (marketable vegetables) using only 65.6% of its current level of irrigation water, while keeping other inputs constant, or that observed level of irrigated production could have been maintained by using the observed values of other inputs while using 34.4% less irrigation water. This means that farmers can achieve significant savings in water use by improving the way they use the irrigation system and by using more advanced irrigations techniques.

Figure 2 gives a graphical representation of the cumulative efficiency distributions for the different measures. Again it is clear that under both returns to scale specifications more farms were highly inefficient in the use of water compared to overall technical efficiency.

**Figure-2.** Cumulative efficiency distribution for both technical and irrigation efficiency under VRS and CRS specification

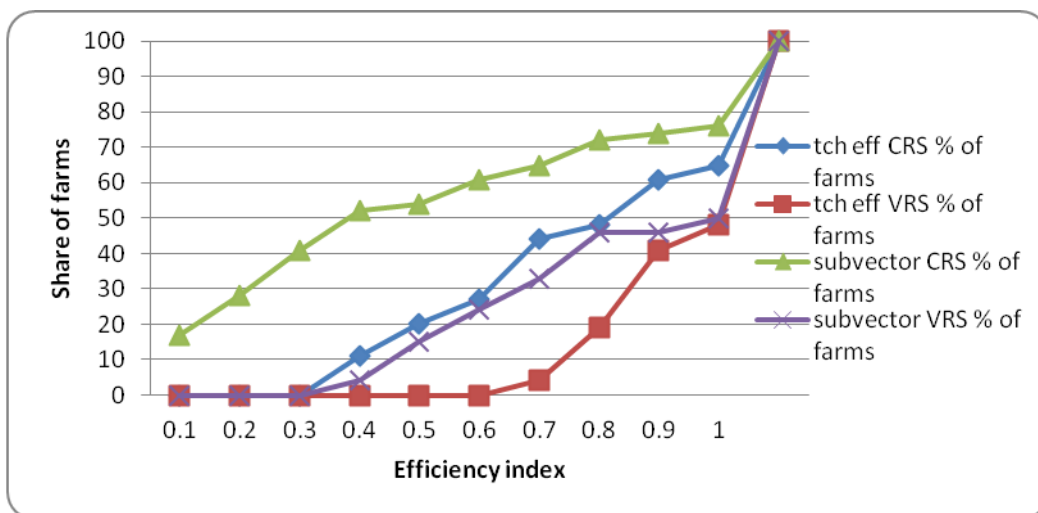


Table 4 gives the correlation statistics between sub-vector efficiency for water and the overall technical efficiency, which help us to determine the relationship between the two efficiency measures. Under CRS and VRS specification, technical efficiency and sub-vector efficiency were highly positively correlated.

**Table-4.** Pearson correlations between efficiency measures.

|          | TE (CRS) | TE (VRS) | IE (CRS) | IE (VRS) |
|----------|----------|----------|----------|----------|
| CRS      | 1        |          |          |          |
| VRS      | 0.136    | 1        |          |          |
| IE (CRS) | 0.433*** | 0.688*** | 1        |          |
| IE(VRS)  | 0.487*** | 0.356*** | 0.444    | 1        |

**Note:** \*\* indicates a 99% significance level

A paired sample t-test to analyses the equality between sub-vector efficiencies and overall efficiencies was statistically significant. Furthermore, irrigation efficiency were significantly lower than overall technical efficiency measures, both under CRS and VRS specification (table 5).

**Table-5.** Paired samples t-tests demonstrating the difference between technical efficiency and irrigation efficiency

|            | Mean difference | Std dev. | t-statistic |
|------------|-----------------|----------|-------------|
| CRS: IE-TE | -0.21           | 0.21     | -7.24***    |
| VRS: IE-TE | -0.16           | 0.19     | 6.21***     |

**Note:** \*\*\* indicates a 99% significance level

Two conclusions arise from our analysis of inefficiency. First, the farmers and agencies that are involved in agricultural development programs need to appreciate there is a technical inefficiency problem. Operating at best practice, farm families would be able to release 28.25% of

all inputs for use in alternative economic activities to generate extra income for family's welfare. Surplus resources such as water could be reallocated to other water demands.

#### 4.2. Farm Specific Factors Related to Farm Inefficiency

The second part of the analysis consists of identifying the characteristics that determine the sub-vector efficiencies for water of these public irrigated farms based on collective wells. Two separate Tobit regressions for CRS and VRS specifications were estimated using the Shazam's Tobit estimation procedure. The results are presented in table 6.

**Table-6.** Tobit regression coefficients (n=46).

| Variables                     | Sub-vector CRS efficiency | Sub-vector efficiency | VRS |
|-------------------------------|---------------------------|-----------------------|-----|
| Constant                      | 0.907 <sup>c</sup>        | 2.06 <sup>a</sup>     |     |
| Age (FA)                      | -2.01                     | -2.52 <sup>b</sup>    |     |
| Education (EDU)               | 1.5 <sup>c</sup>          | 1.42 <sup>b</sup>     |     |
| Agricultural training (AGT)   | -0.32                     | -0.44 <sup>c</sup>    |     |
| Age <sup>2</sup> (FSA)        | 0.025                     | 0.03 <sup>b</sup>     |     |
| Share of family labor (FL)    | 0.01                      | 0.08                  |     |
| Size of farm (FS)             | -0.005 <sup>c</sup>       | -0.006 <sup>b</sup>   |     |
| Equipped irrigated area (EIA) | 0.495 <sup>a</sup>        | 0.56 <sup>a</sup>     |     |
| Log likelihood                | -123.19                   | -134.7                |     |

<sup>a</sup>significant at 1% level, <sup>b</sup>significant at 5% level, <sup>c</sup>significant at 10% level.

The estimated coefficients in the technical inefficiency model are also as expected. The farm size, agricultural training and age negatively influenced water efficiency, while the other significant variables had a positive effect on the efficiency measures. The results in table 6 showed that the farmer's age has a negative, but a positive quadratic effect on all efficiency measures. However, the parameters are only significant for Sub-vector VRS efficiency at the 5 per cent significance level. This suggests that younger farmers are more likely to be inefficient than their older counterparts. The quadratic age variable has a positive coefficient indicating that inefficiency drops with age, perhaps because of the experience. Farm size has a negative and significant effect on inefficiency levels, with suggests that, on average, large farms operate at higher efficiency levels than small farms. Concerning the farmer training (AGT), variable of particular interest to policy maker, had a negative effect under both specifications, but were only significant under the VRS specification. Consequently, the negative and statistically significant at 10% level coefficient suggests that an increase in the training programs related to the irrigated agricultural contributes to higher technical efficiency levels of collective wells production on these farms.

Education (EDU) also has a positive impact on technical efficiency. Schooling helps farmers to use information efficiently since a better educated farmer acquires more information and is able to produce from a given input vector. In addition, the results reveal statistically insignificant but consistently positive relationships between the share of family labour (FL) and all efficiency

measures under both specifications. Finally, the equipped irrigated area (EIA) was highly significant and had a positive effect on the sub-vector efficiency for water under both specifications at 5 per cent significance level.

## 5. DISCUSSION AND CONCLUDING REMARKS

Water demand management is an increasingly crucial issue. So far, irrigation development has allowed Tunisia to ensure up to 35% of its agricultural production whereas recently, decision makers planned a target contribution of 50%. The achievement of such an objective faces some management difficulties related to an increasingly scarce water resource and weak irrigation water use efficiency. Thus the challenge is how to reconcile a sustainable management water resource with an increased production and efficiency target.

Over the past two decades the government has implemented different programs in order to improve the irrigation water use efficiency (IWUE) and to enhance the overall performance of the sector. These concerns have been addressed in terms of water pricing reformulation system, water saving technologies adoption at farm level, collective irrigation systems management modernization and by the transfer of government water management systems to water user associations (hereafter WUAs), which have the responsibility for selling and managing the distribution of water. However, these programs do not lead to significant changes in the irrigation practices (Hemdane, 2002; Chraga and Chemak, 2003) given by a weak level of irrigation water use efficiency (Albouchi *et al.*, 2005; Dhehibi *et al.*, 2007; Frija *et al.*, 2009).

This paper proposes an alternative measure of irrigation water efficiency in south east of Tunisia based on the concept of input-specific technical efficiency, which contrasts with previous physical measures used in the literature. The proposed measure has a pure economic rather than an engineering meaning as it concerns with the managerial capability of farmers rather than the water-saving potentials of each irrigation system. It provides information on how much water use could be decreased without altering the output produced, the technology (including irrigation technology) utilized, and the quantities of other inputs used. The proposed measure explicitly recognizes that each irrigation system could be used inefficiently for several reasons that can be explored through statistical methods. The proposed methodology is applied to a randomly selected sample of 46 vegetable growing farms located in Zeuss-Koutine region (South-east of Tunisia).

Empirical results indicate that irrigation water efficiency is on average much lower than technical efficiency, implying that significant reductions in groundwater waste could be achieved if farms become more efficient in the use of irrigation water, given the present state of technology and inputs use. The results for estimates of technical efficiency (TE) indicate that a 28.25% decrease in all inputs is possible with present state of technology and unchanged outputs, or the same level of output can be reached by only using 71.75% of the used inputs, if technical inefficiency is completely removed. The calculated irrigation water use efficiency (IE) is still low and does not reflect the water-saving orientated policies that have been applied. The mean IE is

49.9% under CRS assumption which is very low, particularly for arid regions such as south eastern of Tunisia with limited water resources. This implies that there exists a potential of 50.1% reduction in water use if all farms operated efficiently. Considering that the mean irrigation water use per farm was 3265.767 m<sup>3</sup>/ha in the study area, this infers that almost the half of water used was “excess”. The result of substantial water inefficiencies were reported also by Dhehibi *et al.* (2007) for irrigated citrus production in Cap Bon (47%), by Albouchi *et al.* (2005) in the Kairouan region (53%) and by Frija *et al.* (2009) in the Teboulba region where IE of small-scale greenhouse farmers was approximately 41.8% under CRS specification. Therefore, Tunisia still has much to do to improve the use and sustainability of its water resources. In these paper the quantification of excess water used /water use efficiency can be utilized in at least two ways by government policies: it’s tangible information that can be transferred to irrigators using excess water. This both highlights the specific problem in arid zone’s but also provides realistic targets and relevant benchmarks that can be used as role models, all of which may help to improve current irrigation. Secondly, the quantified excess can be used to investigate the general impact of other variables on the levels of water excess.

In a second step, the relationship between the sub-vector efficiency for water and various attributes of the farm and farmer was examined. The results of the Tobit models can help policy makers or extension services to better aim efforts to improve water use efficiency. According to our findings the education level (EDU) and agricultural training (AGT) are the main factors associated positively with the degree of irrigation water efficiency. This highlights the need for government policies, through extension activities, to set up training programs on irrigated crops in arid zone in order to raise the current level of water use efficiency and hence the sustainability development.

## 6. ACKNOWLEDGEMENTS

The authors would like to thank the two anonymous referees for their constructive comments and suggestions that helped to improve the contents and the presentation of the paper.

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