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Water use and technical efficiencies in private irrigated perimeters 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 100 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 64%. This implies that output level could be producing by saving 36% of (all) farm inputs. A similar pattern of scores was shown for IE; although in this case the average IE was even lower (47.8%) 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, 52.2% less water irrigation.

Key words: irrigation, technical efficiency, DEA method, irrigation water efficiency, Tunisia

كفاءة إستعمال مياه الري والكفاءة التقنية بالمناطق السقوية الخاصة بالجنوب الشرقي التونسي

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الملخص: تهدف هذه الدراسة العلمية إلى تقيم الكفاءة التقنية (technical efficiency) وإلى اقتراح كفاءة استعمال مياه الري استنادا إلى مفهوم الكفاءة الفنية (Water-use-efficiency) بالمناطق المروية الخاصة بمنطقة الزاس كوتين(الجنوب الشرقي التونسي) وذلك من خلال القيام بدراسة لعينة متكونة من مائة منطقة ري واعتماد طريقة " DEA "(Data Envelopment Analysis) لتحديد هذه المؤشرات التقنية. وكان من أبرز النتائج العلمية المتحصل عليها هو الضعف النسبي للمعدل العام للكفاءة التقنية الذي لا يتعدى نسبة ٦٤% داخل المناطق الزراعية المروية بواسطة الآبار السطحية والاستغلال غير المحكم والمفرط في مياه الري من قبل المزارعين وذلك نظرا للتدني الملحوظ في مستوي المعدل العام لكفاءة استعمال مياه الري الذي لا يتعدى نسبة ٤٩% وذلك بالرغم من جملة المجهودات المبذولة من قبل الدولة منذ بداية التسعينيات للنهوض بقطاع الفلاحة المروية والتصرف الأمثل في الموارد المائة.

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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^3/year, of which 2.7 billion m^3 comes from annual rivers in the north, 0.7 billion m^3 from groundwater in the centre, the plains and the coastal area, and approximately 1.3 billion m^3 from the deep groundwater table mainly in the south (Al Atiri, 2005). 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 and Water Resources, 2004).

Today, about 385 thousand hectares (7% of useful agricultural land) are irrigated in Tunisia. 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 Ghersi, 2004). Therefore, during the recent decades concerns regarding the efficient use of water resources in the country have increased. These concerns have been addressed in terms of collective irrigation systems management modernization, water pricing reformulation system and water saving technologies adoption at farm level (Frija et al., 2009).

In this context, the objective of this paper is to estimate and assess the technical efficiency (TE) and irrigation water efficiency (IE) based on the concept of input-specific technical efficiency of a sample of 100 privates irrigators in Zeuss-Koutine region (south-eastern of Tunisia) using Data Envelopment Analysis (DEA). This choice of the study area is motivated by the expansion of irrigated agriculture, the predominance of private initiative in the development of irrigation (Romagny et al., 2004) and by the overpumping of the Smar and Jorf Aquifers in Zeuss-Koutine regions (MA/DGRE, 2005).

Materials and Methods

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. Farrel (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. Frija et al., 2009; Lilienfeld and Asmild, 2007; Lansink et al., 2002; Speelman et al., 2007). 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 ‘‘water use efficiency’’ or in the case of irrigated production, ‘‘irrigation water efficiency’’ (IE).

Irrigation water efficiency, as previously defined in the literature (McGucrin 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 (McGuckin et al., 1992).

There are two main competing paradigms for estimating the relative efficiency of farms: parametric and non-parametric. The parametric stochastic frontier production function approach (Aigner et al., 1977; Meeusen and van den Broeck, 1977) and the non-parametric approach, commonly referred to as data envelopment analysis (DEA) (Charnes et al., 1978) are the two most popular techniques used in efficiency analysis.

Among many authors, Coelli (1995) presents the most recent review of various techniques used in efficiency measurement, including their limitations, strengths and applications in agricultural production. The main advantages of the DEA approach are that have more flexibility in that they avoid a parametric specification of technology as well as the distributional assumptions of the efficiency, although allowing curvature conditions to be imposed easily (Sharma et al., 1999; Speelman et al., 2007). Consequently, DEA is used in this study to compute input-based measures of overall technical efficiency (TE) and sub-vector technical efficiency (in terms of input use) for irrigated agriculture in south eastern of Tunisia (IE).

Data Envelopment Analysis

Data envelopment analysis (DEA) was developed by Charnes, Cooper, and Rhodes (1978) based on M. J. Farrel’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 (Farrel, 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,……n), each producing M outputs y_{mn} (m=1,…M) by using K different inputs x_{kn} (k=1,…..K), each farm becomes the reference unit. For the i-th firm we have vectors x_i (kx1) and y_i(Mx1). For the entire data set, therefore, we have a KxN inputs matrix X and MxN output matrix Y.

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

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

where θ is a scalar and λ_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 θ is the efficiency scores for each of N farms. The estimated will satisfy restriction $\theta \leq 1$ with a value θ=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 ($\sum_{j}^{n} \lambda_j = 1$). 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:

$$SE_i = \frac{\theta_i^{CRS}}{\theta_i^{VRS}} \quad [1] \tag{2}$$

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 firm i by solving , the following linear programming (LP) problem (3):

$$\theta^t = \min_{\theta,\lambda} \theta$$

s.t.

$$\sum_{j=1}^{n} \lambda_j y_{m,j} \geq y_{m,i}$$
$$\sum_{j=1}^{n} \lambda_j x_{k-t,j} \leq x_{k-t,i} \tag{3}$$
$$\sum_{j=1}^{n} \lambda_j x_{t,j} \leq \theta^t x_{t,i}$$
$$\sum_{j=1}^{n} \lambda_j = 1$$
$$\lambda_j \geq 0$$

where θ^t is the irrigation water efficiency score. θ, 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 θ 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 witch the water use inefficiency of all other irrigators, or amount of "excess water" used, can be measured. As an example, a θ 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.

The difference between the technical and the sub-vector efficiency (in terms of individual inputs) using DEA approach is illustrated in Figure 1, where each dot represents a combinations of input x_1 (water irrigation) and x_2 (other input) used by three farms (A,B1, B2) to produce the same quantity of outputs. In figure 1, the piecewise linear isoquant is constructed from the combinations of x1 and x2 of farms B1 and B2. Therefore, farms B1 and B2 are technically efficient farms. Farm A uses more of x1 and x2 although producing the same output as farm B1 and B2. The observation A is, however, inefficient farm. The technical efficiency of farm A, relative to B1 and B2, is given by the ratio $\theta^t = OA^0/OA$. It should be that this measure of technical efficiency assumes that both input x1 (irrigation water) and input x2 can be radially, i.e. by the same proportion, given by 1-θ. In terms of figure 2, farm A's sub-vector efficiency of irrigation water (input x1) is given by the ratio θ^t = O'A'/O'A. Therefore, farm A could reduce irrigation water by the proportion given by $1-\theta^t$ to reach the frontier. The horizontal distance to the frontier (A'A) represents his excess use of the water input compared to their benchmarks on the frontier which produce the same output using less water. The benchmark is reached by multiplying an observation's water input by its estimated DEA efficiency score θ. If observation A, for example, uses 5 units of water to produce its current level of output, then an estimated θ value of 0.6 would indicate that the benchmark (here a convex combination of observations B_1 and B_2) uses 0.6 x 5 = 3 units of water to produce the same amount of output. The distance between the observation A

[1] θ^{CRS} and θ^{VRS} denote the TE index of the ith firm under constant returns to scale (TE_{CRS}) and variable returns to scale (TE_{CRS}) respectively

and its benchmark A’ indicates the excess water used, which would here be 5-3 = 2 units of water, as compared to a benchmark that produces the same level of outputs. This also implies that A can save 2 units of irrigation water.

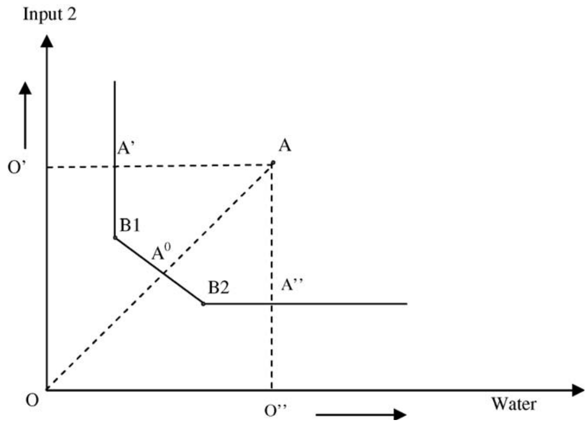

Figure 1. Differences between technical efficiency and irrigation water efficiency input-oriented efficiency
(based on Oude Lansink et al. 2002).

Case study and data collection

We collected our data from small-scale private irrigated farms in the region of Zeuss-Koutine, located in south-eastern area of Tunisia and within governorate of Médenine (Figure 2). In this region irrigation activity is recently introduced and water scarcity is an important issue (Bruno et al., 2004). The groundwater resources are scarce and over exploited. This exploitation reaches 183% with annual renewable resource of 1.39 Mm^3. Two subsystems can be distinguished: the sub-system of private irrigated farms is based on surface wells (655 farms). The subsystem of public irrigation schemes is based on collective tube-wells (158 farms), normally established by the state. The water management is ensured by a water user association known as the ‘GDA’. The agricultural production is based on crop production and the irrigation system is characterised by surface irrigation methods.

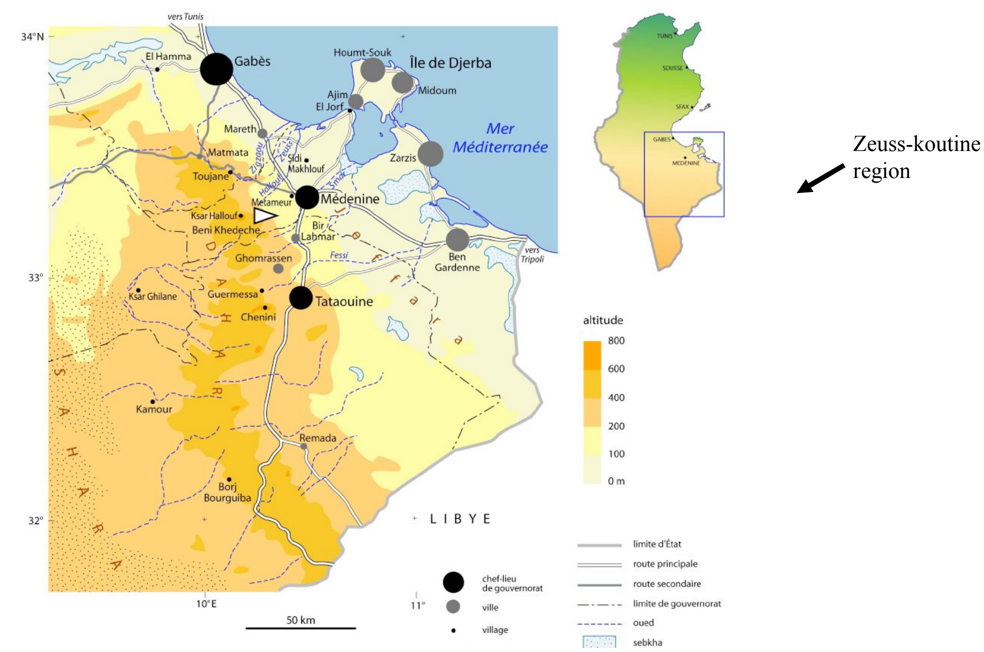

Figure 2. Study area: Zeuss-Koutine region.

The data for this study were taken from a different surveys conducted in the laboratory of Economics and Rural Society between April 2005 and August 2009. A sample of 100 farmers from these surveys was used in this analysis. 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 private irrigated farms surveyed by delegation and by land area.

Delegations	Private farms			
	≤1ha	1-2 ha	>2	Total
Sidi Maklouf	13	18	19	50
Médenine Sud	10	21	19	50
Total study area	23	39	38	100

The selected sample comprises 23 farms smaller than one hectares (23% of the sample), 39 ranging between one and two hectares (39%) and 38 larger than two hectares (38%). It represent 13% (213 ha) of the total private irrigated land area in Zeuss-Koutine region.

These surveys involved a personal interview and it collected quantities and costs of inputs used in production, quantities and value of output, the quantity of water consumed and irrigation practices.

The current study considered the three main crops produced on the farms: cereals, olive tree and legumes. The production data included the output levels of each of these three groups of crops converted into monetary values. Aggregated inputs considered in this analysis are: (1) land measured in hectares, (2) irrigation water measured in m^3, (3) total labor measured in working days, (4) chemicals inputs measured in Tunisian dinars (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 of the variables used in the DEA analysis.

	Output	Inputs				
	Production (in TND)	Land (ha)	Water (m^3)	Labor (days/year)	Chemical inputs (in TND)	Others costs (in TND)
Average	14933.4	2.13	23306.4	1128.89	2091	992
Standard deviation	12016.19	1.31	22998	573.08	2141.41	1266.55
Minimum	1000	0.5	1800	288	35	0
Maximum	60000	9	128304	2957	8999	8900

Note: 1 TND (Tunisian dinar) =0.60 Euros

Results and Discussion

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).

Results for estimates of technical efficiency (TEi) and irrigation efficiency (IEi) are presented in Table 3. 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 27.5% to 100% with an average estimate of 80.3%. This results means that a 19.7% 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 80.3% of the used inputs, if technical inefficiency is completely removed. Thus, improving technical efficiency will significantly increase farm's revenue and profit.

The decomposition of the technical efficiency measure produced estimates of 19.7 percent pure technical efficiency inefficiency and 23.9% scale inefficiency. By eliminating scale inefficiency the farms can increase their average technical efficiency level from 64 to 80.3%.

On the other hand, mean water efficiency is found to 47.8% and 60% under CRS and VRS, formulation, respectively, which is much lower than technical efficiency and also exhibits greater variability, ranging from 1.5% to 100%. Under VRS assumption, the estimated irrigation water efficiency implies that the farms should be able to produce the same level of output using only 60% 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 40% 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.

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

Efficiency (%)	**Technical efficiency (TE)**		**Irrigation efficiency (IE)**	
	CRS Number of farms	VRS Number of farms	CRS Number of farms	VRS Number of farms
0<E<=25	9	0	35	26
25<E<=50	28	10	24	18
50<E<=75	27	30	15	15
75<E<=100	36	60	26	41
N	100		100	
Mean efficiency	64	80.3	47.8	60
Min. efficiency	16	27.5	0.3	1.5
Max. efficiency	1.00	1.00	1.00	1.00
Scale Efficiency	76.1		74.5	

In order to investigate potential differences between TE and IE, table 4 gives their distribution for three identified groups of farms. The first one is the least efficient (i.e. technical efficiency between 0 and 50%), the second is most efficient (technical efficiency between 50% and 75%), and the third is the most efficient overall (technical efficiency between 75 and 100%).

Table 4. Average efficiencies of selected farms, given constants return to scale assumption.

	Average technical efficiency	**Average irrigation efficiency**
Group 1 (0<TE<=50%)	35%	22.58%
Group 2 (50 %< TE<=75%)	62%	60.7%
Group 3 (75%<TE<=1)	95%	90%

The first thing to note about these results is that under constant returns to scale (CRS), the average irrigation efficiency score derived is either less to the average technical efficiency score derived for every groups. In fact, while the average technical efficiency is approximately 95% for the third group, the mean IE of this group is only about 90%. For the first group, the average TE is around 35%; however, IE, for this group is only 22.58%

Figure 3 indicates 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.

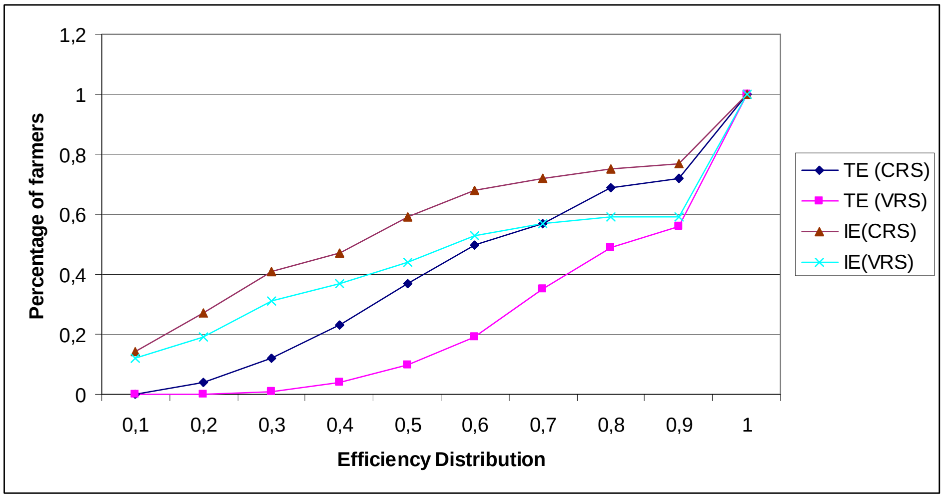

Figure 3. Cumulative efficiency distribution for both technical and irrigation efficiency under VRS and CRS specification.

We will now consider the annual mean water excess across all groups of farms as shown in Table 5. The average water excess ranges from 0 m^3/ ha to 24570.89 m^3/ ha, with an average estimate of 2421.61 m^3/ha under CRS assumption. Considering that the mean irrigation water use per farm was 4652.90 m^3/ha in the study area, this infers that almost half of the water use was “excess”.

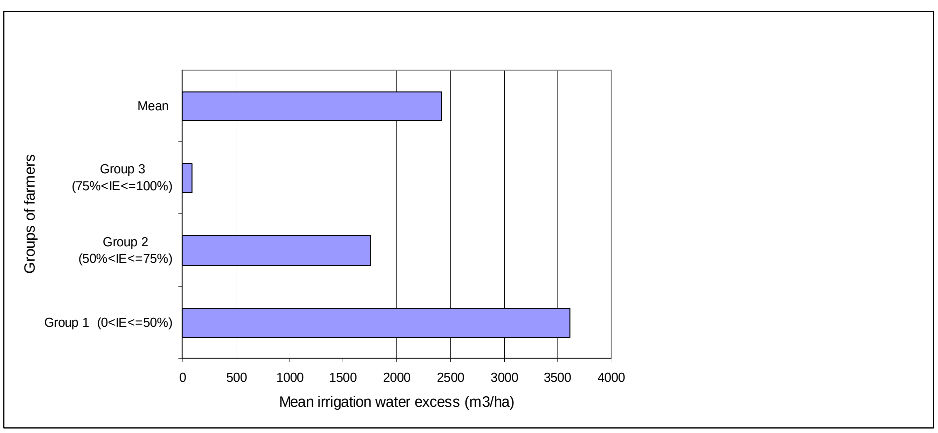

Figure 4. Estimated irrigation water excess (m3/ha) by groups of farmers, given constants return to scale assumption.

The Pearson correlations between TE and IE measures are presented in Table 5. These estimates provide evidence that there is a weak positive correlation between technical efficiency and irrigation efficiency under CRS and VRS specification.

Table 5. Pearson correlations between efficiency measures.

	TE (CRS)	TE (VRS)	IE (CRS)	IE (VRS)
CRS	1			
VRS	0.67**	1		
Sub CRS	0.85**	0.69**	1	
Sub VRS	0.609**	0.875**	0.79**	1

Note: ** indicates a 99% significance level

A paired sample t-test to analyse the equality between IE efficiencies and TE was statistically significant. Furthermore, irrigation efficiency was significantly lower than technical efficiency measures, both under CRS and VRS specification (Table 6).

Table 6. 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 36% 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.

Conclusion and discussion

The study used a DEA approach to measure the technical and sub-vector efficiency for water of irrigated private perimeters based on surface wells in Zeuss-Koutine region, south-eastern Tunisia. The Sub-vector Data Envelopment Analysis has used for the first time to measure technical irrigation water efficiency and to quantify the reduction potential, or excess, of irrigation water used at the farm level in Zeuss-Koutine region. The proposed methodology was applied to a randomly selected sample of 100 irrigated farms.

The results for estimates of technical efficiency (TE) indicate that the estimated mean input-oriented mean technical efficiency under VRS specification ranges from a minimum of 27.5% to a maximum of 100% with the average estimate of 80.3%. This results means that a 19.7% 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 80.3% 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 60% under VRS 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 40% reduction in water use if all farms operated efficiently. Considering that the mean irrigation water use per farm was 4652.90 m^3/ha in the study area, this infers that almost 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 order to enrich this analysis, the source of efficiency differentials between farmers needs to be explained by further research of socio-economic characteristics. This topic has been addressed by other researchers and a common finding is that increase age and educational levels are positively related to technical efficiency (Dhibi et al., 2007; Frija et al., 2009). However, it is worth noting that the present study has some limitations. Because of the need to rely on farmers memories, the efficiency analysis is based generally on a single season. Extrapolating the results to other areas, years and seasons needs to be done with care. Furthermore, factors such as the timing of fertiliser application and irrigation can have an impact on efficiency. Therefore inefficiency is not just a result of the differences in the quantities of land, human labour, seed and mechanical labour, irrigation and chemicals revealed in this research. Also, institutional factors such as extension, systems research and general policies need to be examined. Future research needs to concentrate on developing the appropriate frontier model that encompasses all components of the whole farming systems quality and time variation components. Explicitly incorporating these factors in the analysis can only give rise to improvements in measured efficiency levels.

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