Irrigation water use efficiency in collective irrigated schemes of Tunisia: determinants and potential irrigation cost reduction

By

CHEBIL, Ali; FRIJA, Aymen and ABDELKAFI, Belhassen

Contributed Paper presented at the Joint 3rd African Association of Agricultural Economists (AAAE) and 48th Agricultural Economists Association of South Africa (AEASA) Conference, Cape Town, South Africa, September 19-23, 2010.

Irrigation water use efficiency in collective irrigated schemes of Tunisia: determinants and potential irrigation cost reduction

Ali CHEBIL[(1)], Aymen FRIJA[(2)], Belhassen ABDELKAFI[(3)]

[(1)] Institut National de Recherches en Génie Rural, Eaux et Forêts (INRGREF)

B.P. 10 - 2080 Ariana, Tunisie

Tél. : +216 71 / 719 630 ; Fax : +216 71 / 717 951

Corresponding author : Email: chebil.ali@iresa.agrinet.tn

[(2)] Department of Agricultural Economics

Ghent University

Coupure Links 653, 9000 Ghent, Belgium

[(3)] Ecole Supérieure d'Agriculture de Mograne,
1121 Mograne, Tunisie

Abstract

This study aims first to measure the farm specific irrigation water use efficiency (IWUE), through non parametric DEA model; and second to evaluate the potential irrigation cost reductions and identify the main factors causing variations in IWUE among the sample farms. Cross sectional data collected from a sample of 75 farms participating in the the WaDImena project in Nadhour region (northern Tunisia) was used for this aim. The results showed that the average level of IWUE across the farm sample was around 61.2% under variable returns to scale (VRS) assumption. However, the estimated mean irrigation water technical cost efficiency (ITCE) is much higher than IWUE. Farmers would be able to reduce their actual cost by 5% under VRS by adjusting irrigation water to its efficient level. This low level of cost reductions is consistent with the existing literature about IWUE in Tunisia. Moreover, education level of farmers, access to credit and agricultural extension service showed a positive relationship with the IWUE in our case study.

1. Introduction

During the 1970s and 1980s, the Tunisian government has invested considerable amounts of resources in developing the water system infrastructure and the irrigated public perimeters (IPP). In fact, between 1971-1990, public investment in water systems comprised 40% percent of total investment in agriculture (Sghaier, 1995). This investment aimed to encourage irrigated agriculture and to improve the farm's income. Actually, irrigated area in Tunisia occupies only 8% of total agricultural surface but it generates 35% of the agricultural production value, 20% of exports and 27 % of agricultural employment (Al Atiri R., 2007).

However, the increase of water demand, associated with the rapidly growing population and competition between industrial, domestic, touristic and agricultural sectors, amplified the need for a better management of the resource (Thabet, 2003) to avoid harming the performance of the irrigated sector. In 2030, the overall water demand in the country is expected to exceed its supply (MARH, 1998). To overcome the water shortage, especially in the future, several measures should be taken for conservation of water resources especially in the agricultural sector which consumes more than 80% of the total consumption in Tunisia.

In this respect, reforms were undertaken since the beginning of the 90's in order to improve the irrigation water use efficiency (IWUE) and to enhance the overall performance of the sector. Three important reforms are (i) the modernization of collective irrigation systems management by enhancing the role played by water users associations (WUA) and by promoting the participation of users in all management aspects, (ii) reformulating the water pricing system by introducing the cost recovery objective and (iii) developing incentives to enhance and promote the adoption of water saving technologies at farm level.

The national irrigation water saving program was furthered by the political decision to increase the rate of subsidy for the adoption of modern irigation water saving equipment. The program sets out various actions to improve the IWUE. Despite the fact that the implemented of this program already contributed positively to significant results in terms of IWUE, some recent research studies (Chemak, 2010; Frija et al. 2009; Dhehibi et al. 2007; Albouchi et al., 2007) concerning the IWUE at farm level show that a large potential for improvement of the IWUE exists in Tunisia.

IWUE study is a very important issue, especially for Groundwater resources. In fact, increasing signs of over-exploitation in Tunisia is causing threats to groundwater supplies in terms of depletion and groundwater quality deterioration. Dropping groundwater levels are observed in many parts of our study area located in the central semi-arid Tunisia (Ben Allaya et al., 2009, Abdelkhafi, B.H et al., 2009; Mchabet, 2008). However, major institutional innovations to manage groundwater are absent. Improvements in groundwater use efficiency are an essential element to mitigate water degradation.

This paper aims to examine IWUE and its determinants of vegetable producing farmers in irrigated areas of Nadhour region (Zaghouan)**,** to evaluate the potential irrigation cost savings and to identify the main factors causing variations in IWUE among the sample farms.

In Tunisia, few studies about IWUE have been done in this country using non parametric or parametric methods (Chemak, 2010; Dhehibi et al., 2007). However, in this study, a DEA subvector efficiency model is used to derive the IWUE (Speelman et al., 2008; Frija et al., 2009)

The structure of the rest of this paper is as follows. In section 2 the methodology used will be detailed. Empirical results are presented in section 3. Finally, in section 4 concluding remarks are drawn.

2. Methodological framework

2.1. DEA subvector efficiency for water use efficiency calculation

Efficiency calculation using DEA is based on the simple notion that a production unit which employs fewer inputs than another to produce the same amount of output can be considered as more efficient. The DEA method, used in this study, defines efficiency as the ratio of weighted sum of outputs for a given Decision Making Unit (DMU), to its weighted sum of inputs. For each DMU_k, a non-negative input vector $x^k = (x_{k1},...,x_{kN}) \in R_+^N$ is transformed to a non-negative output vector $y^k = (y_{k1},...,y_{kM}) \in R_+^M$. In an input-oriented DEA model[1] of

[1] Efficiency models in general and DEA techniques in particular, can be inputs or outputs-oriented. The difference lies in whether the objective is to continue producing the same outputs with minimum inputs (input-oriented models) or if the objective is to maximize outputs using the minimum amount of inputs (output-oriented models) (Rodriguez Diaz et al, 2004a).

technical efficiency, the production possibility set (P), which describe also the technology, represent the set of all feasible input-output vectors: $P = \{(x, y) / x \ can \ produce \ y\}$. Simultaneously a production frontier is constructed and efficiency scores for each DMU are calculated.

Practically, the surface constructed over the data, allows the comparison of one production method to the others in terms of performance index. In this way, DEA provides a straightforward approach to calculate the efficiency gap that separates the behaviour of each producer from best practices, based on actual observations of inputs used and outputs generated by efficient firms (See Cooper et al. (2000) for more details about DEA approach).

To calculate the efficiency of use of an individual input or subset of inputs, the "sub-vector efficiency" concept can be introduced. This measure generates a technical efficiency score for a subset of inputs while other inputs are kept constant. The sub-vector efficiency measure looks at the possible reduction in the selected subset of inputs holding all other inputs and outputs constant (Oude Lansink and Silva, 2004; Oude Lansink and Silva, 2003; Oude Lansink et al., 2002; Färe et al., 1994). Following Färe et al (1994) technical sub-vector efficiency for the variable input (*t*) can be determined for each farm i by solving the following alternative DEA model (2) :

$$Min_{\theta^t,\lambda} \theta^t \qquad (1)$$

$$\text{s.t.} \ \sum_{k=1}^{K} \lambda_k y_{m,k} \geq y_{m,o} \qquad (2)$$

$$\sum_{k=1}^{K} \lambda_k x_{n-t,k} \leq x_{n,o} \qquad (3)$$

$$\sum_{k=1}^{K} \lambda_k x_{t,k} \leq \theta^t . x_{t,o} \qquad (4)$$

$$\sum_{k=1}^{K} \lambda_k = 1 \qquad (5)$$

$$\lambda_k \geq 0 \qquad (6)$$

Where θ^t is the input sub-vector technical efficiency score for input t for the DMU_0. The measure θ^t represents the maximum reduction of variable input *t* holding outputs and all remaining inputs (*n*-*t*) constant. All other variables are defined as in model (1).

λ_k is a vector of k elements representing the influence of each DMU in determining the efficiency of the DMU_0. The term $\sum_{k=1}^{K} \lambda_k y_{m,k}$ indicates the weighted sum of outputs of all DMU, which must be superior or equal to the output of DMU_0 (constraint 2). The DMUs whose λ values are positive will be the reference set for DMU_0 under study. In fact, it is the linear combination of those units, which will formulate the objective situation needed to become efficient. In constraint 4, θ^t is the measurement of technical efficiency of water use and represents, at the same time, the minimized objective. Thus, constraint 4 indicates that the value of θ^t to be assessed must shift the production factor (water) towards the production frontier (for a given output level). Equation 5 is a convexity constraint, which specifies variable returns to scale (VRS). The use of the VRS specification will permit the calculation of Technical Efficiency (TE) devoid of these Scale efficiency (SE) effects (Coelli., 1996). In the agricultural sector, increased amount of inputs usually do not proportionally increase the amount of output produced (Speelman et al., 2008). For instance, when the amount of water is increased, a linearly proportional increase in crop volume is not necessarily obtained. For this reason, a variable returns to scale option might be more suitable for efficiency measures in the agricultural sector (Rodriguez-Diaz at al., 2004b) (see Frija et al, 2009 and Speelman et al 2008 for more details about the use of subvector efficiency for IWUE calculation).

2.2. Irrigation water technical cost efficiency

Since IWUE is a non-radial efficiency measure that does not have a direct cost-saving interpretation, the single-factor technical cost efficiency measure could instead be used to evaluate the potential cost savings accruing to more effective management of a single factor (Kopp, 1981). Then, irrigation water technical cost efficiency (ITCE), could be defined as the potential cost savings from adjusting irrigation water to a technically efficient level holding all other inputs at observed levels. Following Akridge (1989), farm-specific estimates of $ITCE_i$ may be obtained as:

$$ITCE_i = S_{wi} IWUE + \sum_{j=1}^{j} S_{ji} \qquad (7)$$

Where S_{wi} and S_{ij} are the i[th] farm's observed input cost shares for irrigation water and the j[th] input, respectively. Given that 0<$IWUE_i$<1 and $S_{wi}+\sum_{j=1}^{j} Sji=1$ for all i, ITCE will be comprised between 0 and 1.

2.3. Tobit model

To study the IWUE and ITCE determinants, the present study uses the Tobit model. Tobit regression is an alternative to ordinary least squares regression (OLS) employed when the dependent variable is bounded from below or above or both either by being censored or by being corner solutions (Wooldridge, 2002). The Tobit model supposes that there is a latent unobservable variable $IWUE^{*}_{i}$. This variable depends linearly on x_i via a parameter vector β. In addition, there is a normally distributed error term u_i to capture random influence on this relationship. The observable variable IWUE is defined as being equal to the latent variable whenever the latent variable is above zero and to be equal to zero otherwise.

In a second stage of this study, a set of socioeconomic characteristics and farms' attributes variables will be selected as potential determinants IWUE and ITCE. Following tobit model can be considered :

$$IWUE=\sum_{i=1}^{I}\beta_i x_i+u_i\ ,$$

where $$IWUE=\begin{cases} IWUE\ if\ < IWUE<1; \\ 0\ if\ IWUE<0; \\ 1\ if\ IWUE>1 \end{cases} \qquad (8)$$

Where IWUE is the technical water use efficiency index used as a dependent variable and X is a (*I*1*) vector of independent variables related to attributes of the farmers/farms in the sample. This tobit model will also be regressed with ITCE as dependent variable.

2.4. Case study and data collection

The study was conducted in six IPP of the Nadhour region, situated in Zaghouan province, which is located on the northern of Tunisia. Nadhour region is facing growing problems of scarcity. It is located in the semi-arid bioclimatic lower floor in moderate winter. The average rainfall in the area is 370 mm/year with high annual variability and the evapo-transpiration is very high. This region is characterised by high temperatures in summer which can achieve 46°C.

The irrigated area under study covers 350 ha. These 6 small scale perimeters include 160 farms. The average surface per farm is about 2 ha. Groundwater represents the only water source is this area. Each PPI has a Tube-well and it is managed by water users' association "*Groupement de Développement Agricole (GDA).* Water salinity is approximately 1.8 and it is suitable for vegetable growing. Drip irrigation is generalised for the vegetable production in the region.

The data collection was conducted during the period August 2007- July 2008 from 80 farmers participated in the the WaDImena Project. The farmers have been monitored during the growing season in order to estimate the quantity of water acquired from *GDA.* Since some farmers didn't grown vegetable in this year, a total of 75 observations were available for the analysis. From each farm it was possible also to obtain demographic characteristics, resources factors and institutional factors.

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, output is aggregated into one category and inputs are aggregated into five categories, namely, seeds, water, fertilisers, pesticides and mechanisation.

Presented below is a summary statistics of variables used in DEA model. The farmers involved in the study have relatively small farms. The mean, standard deviations (SD), min and max levels of total product and inputs are shown in Table 1. As can be seen, on average each farmer cultivated 2 Ha of land for vegetable and used 6966 m3. The annual vegetable production value is 10775 Tunisian National Dinar (TND) per farm ranging from a low 2500 to a high of 39000.

Table 1 . Summary statistics of the sample variables

Variables	Mean	Minimum	Maximum	SD
Value of output (TND)	10775.00	2500	39000	6986.64
Water (m3)	6966.81	987	24344	5097.34
Land (Ha)	2.03	0.5	7	1.42
Seeds (TND)	1088.46	126	6405	1138.84
Fertilisers (TND)	2113.16	465.75	7217	1393.62
Pesticide (TND)	274.66	39	993	219.14
Mechanisation (TND)	478.70	90	1632	333.54
Labour (TND)	979.09	184.50	3352	696.35

1 TND≈0.78$

In the Tobit analyses various farmer/farm specific factors regressed on the subvector efficiencies for water. The choice of tobit model is because the values of dependent variable are censored variables, having an upper limit of 1. IWUE are likely to be affected by a wide range of variables. These may include (biological factors, human resources, socioeconomic condition and institutional variables. The following variables are considered in the Tobit model estimation:

- Farmer's age is used as a proxy variable for measuring general farming experience (years)
- Education level : dummy = 1 if the farmer has education up to primary, 0 otherwise
- Land tenure: Share of owned land (%)
- Total farm size (ha)
- Contact to agricultural extension service: dummy = 1 if farmer contact with agents, à otherwise
- Acces to credit (dummy = 1 if farmer had taken agricultural credit, 0 otherwise)

3.Empirical results

3.1DEA results

DEA models are estimated using program GAMS. The overall technical efficiency (TE), irrigation water efficiency and ITCE measures, under the assumption of CRS and VRS, are summarised in Table 2. The estimated mean TE measure for the sample vegetable farmers is 81.56% for the VRS DEA model and 73.11% for the CRS DEA model. This result reveals inefficiency in the use of inputs, which means that the current level of output can be produced using 18.44 % (26.89%) less inputs on average than are applied by farmers under VRS assumption (respectively, CRS). In terms of TE, 20 of the 75 farms investigated are fully efficient under the VRS model. Under the CRS model, only 11 farms are fully efficient. The difference between the VRS and CRS measures further indicated that many farms did not operate at an efficient scale and that adjusting the scale of operation could improve the efficiency.

The mean IWUE from the DEA frontier are, respectively, 61.2% for VRS and 50% for CRS, which is much lower than TE and it also exhibits greater variability ranging from 18.5% to 100 under CRS and 13.8 % to 100 under CRS. The estimated mean IWUE implies that the observed value of vegetable production could have been maintained by using the observed values of other inputs while using 38.8% (50%) less of irrigation water under VRS assumption (respectively, CRS). This means that the majority of farms can achieve significant savings in water use if know-how of the utilised irrigation system is improved.

This large potential to increase IWUE are on line with the results of Chemak (2010) on Sidi Bouzid farmers (Tunisian semi-arid region), Dhehibi et al. (2007) on citrus producing farms in Cap Bon region and Frija et al. (2009) on horticultural greenhouses in Tunisia.

Therefore, the results show that inputs, especially irrigation water, for some farmers could be saved without harming their production. These results reconcile a sustainable management water resource. In fact, the overexploitation in the irrigated area is about 20% (Ben Allaya et al., 2009). This strategy decrease the overexploitation of the groundwater and goes with a sustainable use of the resource.

The potential cost reductions that could be attained by adjusting irrigation water to its efficient level would be small since its outlays constitute only a small proportion of the total cost. For this reason, the estimated mean ITCE is much higher than IWUE. By reaching full water efficiency levels, farmers would be able to reduce their actual cost by 5% under VRS and 6.3% under CRS (Table 2). This low level of cost reductions is in line with the reuslts of Dhehibi et al. (2007) and Karagiannis et al. (2003).

Table 2: Frequency distribution of efficiency ratings of vegetable farms in Nadhour

Efficiency (%)	TE		IWUE		ITCE	
	VRS	CRS	VRS	CRS	VRS	CRS
<30	0	0	8	14	0	0
30-40	2	4	14	23	0	0
40-50	2	7	9	14	0	0
50-60	7	6	11	4	0	0
60-70	6	17	10	5	0	0

70-80	14	15	2	2	0	0
80-90	14	9	3	2	1	8
90-100	10	6	0	0	56	56
100	20	11	18	11	18	11
Mean (%)	81.56	73.11	61.25	49.95	94.96	93.77
Minimum (%)	35.91	31.02	18.49	13.77	89.02	85.00
Maximum (%)	1	1	1	1	1	1
Standard deviation (%)	17.51	19.07	26.70	25.34	3.49	3.57

3.2. Factors results

In order to identify factors associated with IWUE, the Tobit model defined in equation 8 is estimated and results are presented in Table 3 . A variable returns to scale option might be more suitable for efficiency measure in agricultural systems and will thus be used in this application.

The software package LIMDEP 7.0 was used to carry out maximum likelihood estimation of the 6 parameters of the tobit model. Given the high correlation between IWUE and ITCE, the signification level of the coefficient are the same. The tobit model results for IWUE is used for interpretation.

Table 3: Factors affecting irrigation water use efficiency of vegetable producing farms in Nadhour

	IE	
	Coefficient	t-ratio
Constant	0.4787899	1.24
Age	0.0023173	0.50
Education	0.2007236*	1.67
Land tenure	-0.0020273	-0.86
Farm size	-0.0162546	-0.63
Extension contact	0.1846955**	2.10
Access to credit	0.2083649*	1.74
LR	15.97**	

Note: ** significant at 5% level
* Significant at 10% level

The null hypothesis that all nonintercept coefficients of the explanatory variables were zero was rejected at 5% level according to likelihood ratio (LR) test. Concerning the individual variables, results of the Tobit model showed consistency. Level of education, contact to agriculture extension service and access to credit are individually significant determinants of

IWUE at 5% level. However, farmer's age, share of owned land and farm size did not significantly influence IWUE .

Education level variable have positive and significant impact on IWUE as expected coefficients. The extension variable has a positive sign and is also statistically significant. This result show that the farmers who are in touch with agricultural extension department in order to seek advice are more efficient in water use.

The positive coefficient of access to credit variable is implying that the relaxation constraint of the farmers increases water use efficiency. The credit availability helps farmers in buying inputs and thus their application at the proper time.

4. Conclusion

This paper presented a methodology for estimating irrigation water use efficiency for individual farms using subvector DEA approach and tested whether particular farm-specific factors are associated with differences in IWUE. Our results suggest that, on average, farms achieve around irrigation water efficiency 61% for VRS and 50% for CRS. The results show that some farmers may reduce their water consumption without harming their production. This strategy decrease the overexploitation of the groundwater and goes with a sustainable use of the resource.

The estimated mean irrigation water technical cost efficiency is much higher than irrigation water use efficiency. By reaching full IWUE levels, farmers would be able to reduce their actual cost by 5% under VRS and 6.3% under CRS. This result is corroborated by findings of other similar studies (Dhehibi et al. 2007 and Karagiannis et al. 2003).

The paper investigated a number of factors associated with higher irrigation water use efficiency scores. Education level of farmers, access to credit and agricultural extension service are important policy variables and determinants of water use efficiency which can be incorporated into the agricultural policy in Tunisia in order to raise the current level of water use efficiency and hence the sustainability development.

Acknowledgements
This work was supported by the project « The water demand initiative for the Middle East and North Africa - WaDImena » Funded by the International Development Research Centre.

References

Abdelkafi B. et al. 2010 Référentiel technico-économique : Projet de recherche-développement « Le suivi de gestion des exploitations et de la nappe pour un développement durable dans les perimeters irrigués de la région de Nadhour» Zaghouan, Tunisie.

Akridge, JT, 1989. Measuring productive efficiency in multiple product agribusiness firms: A dual approach. American Journal of Agricultural Economics 71, 116–25.

Al Atiri R. 2007. Evolution institutionelle et réglementaire de la gestion de l'eau en Tunisie, Vers une participation accrue des usagers de l'eau ; in Sami Bouarfa, Marcel Kuper, Abdelhafid Debbarh (ed) 2007. L'avenir de l'agriculture irriguée en Méditerranée. Nouveaux arrangements institutionnels pour une gestion de la demande en ea. Actes du séminaire Wademed, Cahors, France, 6-7 novembre 2006. CIRAD, Montpellier, France.

Albouchi, L., Bachta, M.S., Jacquet, F., 2007. Compared production efficiency in irrigated areas within a watershed. New Medit, Vol. VI - n. 3/2007

Banker, R. D., Charnes, A., Cooper, W.W., 1984. Some Models for Estimating Technical and Scale Inefficiencies in Data Envelopment Analysis. Manag Sci. 30, no. 9, 1078-1092.

Ben Alaya, A, Mchabet, M., Abdelkhafi, B.H., and Saï, M.B. (2009). Maximation de la marge brute et exploitation rationnelle des eaux souterraines pour une agriculture durable en zone semi aride : Cas d'un périmètre irrigué de la région de Nadhour en Tunisie. Communication présentée à l'occasion de la « 12ème Conférence Inter Régionale Enviro Water et Atelier sur l'Economie de l'Eau » qui a eu lieu à Marrakech (Maroc), du 9-11 novembre 2009

Bravo-Ureta, B.E., Solis, D., Moreira Lopez, V.H., Maripani, J.F., Thiam, A., Rivas, T., 2007. Technical efficiency in farming: a meta-regression analysis. J. Prod Anal, 27, 57-72

Chebil, A., Thabet, C., Frija. A., 2007. Evaluation du prix maximum de l'eau d'irrigation dans les cultures sous serres de la région de Teboulba : Une approximation contingente. New Medit. Vol VI, no. 2, 21-26.

Chemak, F., Boussemart J.P. and Jacquet F. (2010). Farming system performance and water use efficiency in the Tunisian semi-arid: data envelopement analysis. International Transactions in operational research, 17, 381-396

Coelli. T., 1996. A Guide to DEAP Version 2.1: A Data Envelopment Analysis (Computer) Program. Centre for Efficiency and Productivity Analysis CEPA. Working Paper number 96/08.

Cooper, W.W.; Seiford, L.M. & Tone, K. (2000). Data Envelopment Analysis: A comprehensive text with models, applications, references and DEA-solver software. Kluwer Academic Publishers, Boston/Dordbrecht/London.

Dhehibi, B., Lachaal, L., Elloumi, M., Messaoud, A., 2007. Measuring irrigation water use efficiency using stochastic production frontier: An application on citrus producing farms in Tunisia. AfJARE. 1, no. 2, 99-114.

Färe, R., Grosskopf, S., Lovell, C.A.K., 1994. Production frontiers, Cambridge, Cambridge University Press.

Frija A, Chebil A**,** Speelman S, Buysse J, Van Huylenbroeck G. 2009. Water use and technical efficiencies in horticultural greenhouses in Tunisia, (in English). "*Agricultural Water Management", Vol 96(11), 1509-1516, doi:10.1016/j.agwat.2009.05.006* .

Karagiannis, G, Tzouvelekas, V & Xepapadeas, A, 2003. Measuring irrigation water efficiency with a stochastic production frontier: An application to Greek out-of-season vegetable cultivation. Environmental and Resource Economics 26, 57–72.

Kopp, R.J, 1981. The measurement of productive efficiency: A reconsideration. Quarterly Journal of Economics 96, 477–503.

Ministère de l'Agriculture et des Ressources Hydrauliques MARH (1998). Eau 21, Stratégie du secteur de l'eau en Tunisie à long terme 2030 .

Mchabet, 2008. Modélisation numérique de l'hydrodynamique du système aquifère « Nadhour-Saouaf-Sisseb-El Alem »; Mémoire de mastère; Ecole Supérieure d'Agriculture de Mograne; Tunisie; 132 p

Oude Lansink, A., Pietola, K., Bäckman, S., 2002. Efficiency and productivity of conventional and organic farms in Finland 1994-1997. Eur Rev Agric Econ. 29, no. 1, 51-65.

Oude Lansink, A., Silva, E., 2003. CO2 and energy efficiency of different heating technologies in Dutch Glasshouse Industry. Environmental and Resource Economics. 24, 395-407

Oude Lansink, A., Silva, E., 2004. Non-parametric production analysis of pesticides use in the Netherlands. Journal of productivity analysis. 21, 49-6.5

Rodríguez Díaz, J.A., Camacho P.E., López Luque, R., 2004a. Applying Benchmarking an Data Envelopment Analysis (DEA) Techniques to irrigation districts in Spain. Irrig Drain. 53, 135-143.

Rodríguez Díaz, J.A., Camacho P.E., López Luque, R., 2004b. Application of Data Envelopment Analysis to Studies of Irrigation Efficiency in Analusia. J. irrig. drain. eng. 130, 175-183.

Sghair, M. 1995. Tarification et allocation optimale de l'eau d'irrigation dans les systèmes de production de la région oasienne de Nefzaoua (sud de la Tunisie). Ph.D. Thesis, Gent University, Belgium.

Speelman S, D'Haese M, Buysse J, D'Haese L., 2008. A measure for the efficiency of water use and its determinants, a case study of small-scale irrigation schemes in North-West Province, South Africa. Agricultural Systems: In Press. doi:10.1016/j.agsy.2008.03.006 .

Thabet, C. 2003. Réforme de la politique des prix de l'eau d'irrigation en Tunisie : approche en équilibre général. Ph.D. Thesis, ENSA de Rennes, France.