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Water use and technical efficiencies in horticultural greenhouses in Tunisia

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ABSTRACT

We measure the technical efficiency of unheated greenhouse farms in Tunisia, and propose a measure for irrigation water use efficiency (IWUE) using an alternative form of the data envelopment analysis (DEA) model. Technical efficiency measures the degree to which (all) farm inputs are used efficiently. IWUE is a measure of the efficiency of irrigation water use when other inputs and output are kept constant. As a second stage, a *tobit* model is used to identify the degree to which technical efficiency and IWUE correlate with a set of explanatory variables. A comparison of the efficiency scores obtained from constant returns to scale (CRS) and variable returns to scale (VRS) specifications shows that most farmers in our sample are producing at an efficient scale. Under the CRS assumption, the average technical efficiency of the sample was 67.3%. A similar pattern of scores was shown for IWUE; although in this case the average IWUE was even lower (42%). This implies that when all other inputs remain constant, the current output could be produced using, on average, 58% less irrigation water. We conclude that farmers' technical training in greenhouse management, investments in water saving technologies and the existence of a fertigation technique on farm have a significant and positive effect on their level of IWUE. However, IWUE is significantly and negatively affected by the proportion of total farm land allocated to greenhouses.

1. Introduction

The North African countries located in the Southern Mediterranean region are among those that experience the most severe water shortages and face the greatest challenges in terms of future water availability. Most of these countries have a semi-arid climate with limited and variable rainfall. Moreover, much of the rainfall is lost through evaporation (Hamdy and Lacirignola, 1999). During the last three decades, it has been common policy in these North African countries to develop irrigation infrastructure and to control renewable water resources to increase stability in terms of water supply (Ben Mechlia, 2004). Agriculture, being an important component of food security policies, is the main consumer of this supplied water. On average, agriculture accounts for around 80% of total water consumption in Tunisia, Morocco, and Algeria. However, these supply policies have led to substantial use of irrigation water at heavily subsidized cost (Thabet et al., 2005). In the early 1980s, there was a shift in agricultural water policies towards demand management. This alternative has been widely applied at a global level and involves rationalization of the current demand, instead of increasing the current supply. In other words, this means greater efficiency in the allocation and use of water in agriculture.

Rainfall in Tunisia varies greatly, ranging from an average of less than 100 mm year^{-1} in the South, to more than 1000 mm year^{-1} in the extreme north of the country. In the north, however, the topography is mountainous, leaving relatively little cultivable land in the high rainfall areas. As a result, most agricultural activity is undertaken in areas with limited and highly variable rainfall, making irrigation necessary to stabilize or increase production by reducing climatic uncertainty.

Currently, almost 385,000 ha (7% of useful agricultural land) are irrigated in Tunisia. The irrigation sector consumes 80% of the available water resources and provides 35% of the agricultural production value, 95% of horticultural crops, 30% of dairy production, almost 22% of agricultural sector exports, and 26% of total agricultural employment (Ministry of Agriculture and Water Resources, 2004). Moreover, the demand for irrigation water continues to rise, due largely to the development of new irrigation projects and the intensification of irrigation within existing areas. Therefore, during recent decades concerns regarding the efficient use of water resources in the country have increased. These concerns have been addressed in three ways: (i) modernizing the management of collective irrigation systems by enhancing the role played by water users' associations and by promoting user participation in all aspects of management, (ii)

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reformulating the water pricing system by introducing a cost recovery objective and (iii) developing incentives to enhance and promote the adoption of water saving technologies at farm level (Al Atiri, 2004).

In this context, we analyse the current performance of irrigation water use efficiency (IWUE) and its determinants at the farm level in Tunisia. We focus on small-scale irrigated greenhouse production schemes in the Tunisian "Sahel" region. This choice is motivated by the socio-economic importance of greenhouse production in the region, the constraints on water resources and the increasing price of irrigation water. Our methodology is data envelopment analysis (DEA), which enables us to examine the efficiency of an individual input (i.e. water), while keeping other inputs constant. We use a *tobit* model to assess the effects of socio-economic and structural variables on the levels of technical and irrigation water use efficiencies obtained.

2. Methodology: efficiency assessment using data envelopment analysis

The measurement of technical efficiency is based upon deviations of observed output or input vectors from the best production or efficient production frontier. If a production units' actual production point lies on the frontier it is perfectly efficient. If it deviates from the frontier then it is technically inefficient, with the ratio of the actual to potential production defining the level of efficiency of the individual firm. Our measure of technical efficiency provides an indication of how the use of all inputs can be minimized in the production process of a given farm, while continuing to produce the same level of output.

Additionally, we consider the possible reduction of a subset of inputs while keeping other inputs and the output constant. This generates a "sub-vector efficiency" measure. If this is applied to the possible reduction in water use the efficiency measure produced can be called "water use efficiency" or in the case of irrigated production, "irrigation water use efficiency" (IWUE).

Parametric and non-parametric methods are the two main approaches used to measure technical efficiency. The results from both methods are highly correlated in most cases (Wadud and White, 2000; Thiam et al., 2001; Alene and Zeller, 2005), indicating that both methods are valuable and the choice can be based on a researcher's preference. A major advantage of non-parametric DEA for this study is that the calculation of sub-vector efficiency for irrigation water use is relatively straightforward (Speelman et al., 2008).

2.1. DEA models

Farrell (1957) introduces the relative efficiency concept, according to which, the efficiency of a decision making unit (DMU) can be evaluated by comparing it to the other DMUs in a given group. This concept was extended by Charnes et al. (1978) who developed the first DEA model, called CCR (Charnes, Cooper and Rhodes), to incorporate many inputs and outputs simultaneously. In this way, DEA provides a straightforward approach for calculating the efficiency gap between the actions of each producer and best practices, inferred from observations of the inputs used and the outputs generated by efficient firms (Wadud and White, 2000; Malano et al., 2004; Haji, 2006). Explicitly, DEA uses piecewise linear programming to calculate the efficient or best practice frontier of a sample of DMUs. The DMUs on this technical efficiency frontier will have an efficiency score equal to 1. Less efficient DMUs are measured in relation to the efficient ones. Moreover, different units of measurement for the various inputs and outputs can be combined within the DEA models.

The first DEA CCR model assumed constant returns to scale (CRS). For a DMU producing an output Y, using an input X, it is feasible to produce aY using aX amount of input (a is a scalar). However, in practice this may not always be observed, as increasing the input does not usually result in a proportionate increase in output (Speelman et al., 2008). For instance, when the amount of irrigation water is increased, there is not always a proportional increase in crop volume. For this reason, a variable returns to scale (VRS) option might be more suitable for technical efficiency measures in the case of irrigated farms (Rodríguez Díaz et al., 2004b). The first DEA model used to assess technical efficiency under the VRS assumption was developed by Banker et al. (1984) and was called the BCC (Banker, Charnes and Cooper) model.

To identify whether CRS or VRS applies to production using the DEA technique, we calculate and compare the efficiency values under both assumptions. The use of the VRS specification permits the calculation of technical efficiency (TE) without the scale efficiency (SE) effects (Coelli, 1996). According to Coelli et al. (2002), scale efficiency can be obtained by the ratio TE_{CRS}/TE_{VRS}. Obtaining similar values for CRS and VRS efficiencies for a given farm demonstrates high scale efficiency. For this reason we consider both assumptions in this study.

The study of efficiency using DEA can be orientated toward inputs or outputs. The difference lies in whether the objective is to continue using the same amount of inputs while producing more output (output-orientated DEA), or to produce the same amount of output with fewer inputs (input-orientated DEA). We choose input orientation because, in the context of increasing water scarcity, it is more relevant to consider potential decreases in water use than increases in output (Rodríguez Díaz et al., 2004a). Following the Banker et al. (1984) BCC–DEA model, and considering a dataset of K farms ($k = 1, \ldots, K$), each of them using N inputs x_{nk} ($n = 1, \ldots, N$), for producing M outputs y_{mk} ($m = 1, \ldots, M$), each farm becomes the reference unit. We then solve the following linear program (1) K times (once for each farm). The model specification (1) is the dual form of an equivalent primal model specification that maximizes the outputs for given inputs. In applied analysis the dual specification is preferred because it involves fewer constraints. For a general exposition of primal and dual DEA models see, e.g. Coelli et al. (1998):

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

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

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

$$\sum_{k=1}^{K}\lambda_k = 1 \qquad (4)$$

$$\lambda_k \geq 0 \qquad (5)$$

where θ represents technical efficiency and hence the percentage of radial reduction to which each of the inputs is subjected; λ_k is a vector of k elements representing the influence of each farm in determining the technical efficiency of the farm under study ($farm_0$), x_{n0} and y_{m0} are, respectively, the input and the output vectors of the $farm_0$. The equation $\sum_{k=1}^{K}\lambda_k = 1$ is a convexity constraint, which specifies the VRS framework. Without this convexity constraint, the DEA model will be a CCR model describing a CRS situation.

The concept of "sub-vector efficiency" is introduced to account for a specific IWUE score for each farm (Speelman et al., 2008; Lilienfeld and Asmild, 2007; Oude Lansink and Silva, 2004; Oude Lansink et al., 2002; Färe et al., 1994). This IWUE score θ^t for a given