A Stochastic Frontier Approach for Measuring Technical Efficiencies of Date Farms in Southern Tunisia

Mounir Belloumi and Mohamed Salah Matoussi

The main objective of this research is to compare estimates of technical efficiency obtained from the stochastic frontier approach for two samples of farmers of private and water user associations in the Nefzaoua Oases region (Tunisia), which are characterized by a severe scarcity of water and especially a high degree of salinity. Technical inefficiency effects are modeled as a function of farm-specific socioeconomic factors. Results suggest that both systems are technically inefficient. On average, the private system is found to be slightly more efficient than the associative one. Date yield could be explained mainly by four variables: water quantity applied per palm tree, labor per palm tree, phosphate per palm tree, and water salinity. Output elasticities of all inputs are found to be positive and significant except for the farmyard manure. Water salinity has a considerable negative impact on date productivity. For the technical inefficiency model, none of the socioeconomic variables seem to matter.

Key Words: salinization, private and GIC systems, technical efficiency, Nefzaoua oases, date production, groundwater management

The Nefzaoua region is situated in the southwest of Tunisia under arid climatic conditions where the annual mean precipitation is 100 mm and the temperature exceeds 40 degrees Celsius (104 degrees Fahrenheit) in summer. It is an important source of date production in southern Tunisia, contributing up to 45 percent of total area under date production and more than 55 percent of total date production each year. The Nefzaoua Oases region is famous for the production of high-quality dates known as "Deglet Nour." At the turn of the century, Tunisia was selling more than 20,000 metric tons on the world market, which accounted for more than half of Africa's total date exports or 10 percent of the total Tunisian agricultural export market value (Food and Agriculture Organization 2004). Date production in the Tunisia oases has increased significantly over the past three decades, due to expansion in the irrigated area as well as massive investments in irrigation development made by the government. Date production has increased from 58,800 tons in 1975–76 to 107,000 in 2001–02.

The source of irrigation in this entire region is the North-West Sahara Aquifer System (NWSAS). This system is one of the largest groundwater systems in the world. It consists of two main aquifers, the Terminal Complex (TC) and the underlying Intercalary Continental (IC), and covers in total an area of more than 10^6 km². It is shared as a resource by three countries: Algeria, Tunisia, and Libya. Both subterranean reservoirs were filled with fresh water during the wet quaternary period. The TC aquifer is lying under the entire Nefzaoua and formed by many sub-aquifers lying between 300–600 m in depth. It covers 350,000 km² of septentrional Sahara area. The important part is in Algeria. This aquifer has a different piezometric level depending on the thickness of the aquifer, which increases from the Djebel Tebaga to the southwest.

Mounir Belloumi is Assistant Professor of Economic Sciences in the Faculty of Law, Economics, and Political Sciences at the University of Sousse in Sousse, Tunisia. Mohamed Salah Matoussi is Professor of Economic Sciences in the Faculty of Economic Sciences and Management at the University of El Manar in Tunis, Tunisia.

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The IC aquifer is also formed by three sub-aquifers, lying between 1,000–2,200 m in depth. It covers 600,000 km² of septentrional Sahara area. The important part is in Tunisia. Its water has a temperature of +65°C (+149°F). It is fed only from the extremities of the Saharan basin. Its formation seems to have happened in the quaternary precipitation periods. Isotopic dating shows ages between 28,000 and 42,000 years (Kassah 1996, Mamou and Kassah 2002).

The bulk of the water pumped from the system is utilized for the irrigation of approximately 14,000 km² of agricultural land. The present situation can be characterized as fossil groundwater mining, the total extraction being 80 m^3/s. While the stored amount of water would be able to sustain this extraction for another 10,000 years, the water comes at a price. On the one hand, there is the cost of pumping and the investment in wells and pipelines. On the other hand, the cones of depression created by the pumping lead to a deterioration of the water quality of the TC aquifer due to the attraction of saline waters from different sources, such as the brine of the Chotts, the saline water of the underlying aquifers—i.e., the Turonian and the IC—and the seawater of the Mediterranean.

Over the last fifty years, the pumped quantity in Nefzaoua has been increased sixfold, while the irrigated area has tripled. Government-induced expansion of irrigated agriculture as well as uncoordinated growth of private farming activity has induced a considerable overexploitation of the fossil groundwater basins. Over time, the increase in pumping has had negative impacts. First, pumped groundwater quality started to deteriorate with ongoing resource mining. Second, irrigation led to an increase of the shallow groundwater table. For example, piezometric levels of the TC aquifer have been declining in the Nefzaoua region at an average rate of 1 m/year over the past 30 years.

The most plausible sources of salinity are three. The Chott El Jerid has to be viewed as the first one. As already stated, it contains very saline groundwater within its tertiary and quaternary sediments. A pronounced density layering is present with total dissolved solids (TDS) ranging from 10 g/l up to 350 g/l. In an undisturbed state, the elevated TC head relative to the shallow groundwater piezometry prevented any significant downward percolation of phreatic groundwater. Before the end of the 1970s, water flow was artesian. This brought up the idea that leaching was upwards due to the high water table level of the local oasis aquifer. The irrigation water flows in the oases' local drains and from there by the natural drain to the Chott Jerid. The salt could not go back into the aquifers by this process due to the high water table level. Since the 1980s, progressive groundwater mining lowered the TC head, leading to an inversion of the hydraulic gradient in the TC. The gradient inversion has caused an infiltration of Chott water into the TC.

Second, the water of the Turonian shows increased salinity in Nefzaoua. Measured TDS values range from 2.5 to 7 g/l in the southeastern part of Nefzaoua. This also holds true for the IC in Nefzaoua. Measured TDS in this aquifer range from 2.5 to 4 g/l. It is likely that salinization of the TC occurs where interactions between these aquifers exist. The higher pressure head of the Turonian allows its water to leach upward. With a lowered piezometric level of the TC and a still quite unchanged level of the Turonian, this upwelling might be increased, leading to a density layering in the basal zone of the TC formation.

Third and finally, agricultural drainage water may pollute the phreatic oasis aquifer from which water with an increased salt load can percolate into the TC. In areas of inadequate drainage, capillary rise of groundwater resulted in salt accumulation in the topsoil. The low terrain gradient makes adequate drainage particularly difficult. Consequently, salinity of pumped water has risen to unacceptable values in certain areas, thus rendering this water no longer suitable for irrigation purposes.

Besides the global management task for the whole basin, a number of sub-problems on a more local scale have arisen. For that purpose, the Nefzaoua Oases region is studied. Many studies were launched in attempts to localize the origin and the rate of the salinization in the Nefzaoua oases. Among these is the UNESCO North African Aquifer study, in which the regional aquifer was described and modeled (Mamou and Hlaimi 1999). In order to assess the future impact of pumping on the TC aquifer in the Nefzaoua over the next fifty years, a groundwater flow model was developed by Chiang and Kinzelbach (2001). The development and calibration of the model are described in detail by Kriaa (2003). The simulation results of this model show that present pumping schemes for the Nefzawa region are unsustainable. All scenarios investigated show a strong decline in the general piezometric levels. Also, a groundwater simulation model was developed for the whole NWSAS basin to predict the impact of the long-term application of existing and planned extraction projects on groundwater quality (Observatory of the Sahara and the Sahel 2003). All these studies look only at the physical aspects of the Nefzaoua region. However, our study takes into account both the physical and socioeconomic aspects of the region.

Two types of oases systems in Nefzaoua can be distinguished: private and public. Public systems are characterized by water allocation mechanisms following the participatory approach. These systems are organized in water user associations (named locally GIC).

The mobilization of water resources has already peaked for technical, economic, and environmental reasons, whereas the demand, as a result of economic, urban, and demographic progress, is exponentially increasing. The only strategy which seems to work in facing this challenge would consist in setting up radical changes in the management of water resources. Our results could be useful in considering future policies for enhancing agricultural productivity through improved irrigation management. They will be particularly relevant in addressing numerous questions facing irrigation managers, such as the following:

- What is the impact of water salinity on date production?
- What is the relative performance of the farmers? In particular, are the farmers in the GIC system more technically efficient than those in the private system?

The main objective of this research is to answer such questions by inquiring into the efficiency of the productive system. Our methodology will be based on the estimation of the stochastic production function model with technical inefficiency effects (Battese and Coelli 1995).

Frontier production function models have been applied in a considerable number of empirical studies in agricultural economics (Battese and Corra 1977, Lee and Tyler 1978, Stevenson 1980, Pitt and Lee 1981, Kalirajan 1981, Jondrow et al. 1982, Kalirajan 1982, Bagi and Huang 1983, Kalirajan and Flinn 1983, Huang and Bagi 1984, Schmidt and Sickles 1984, Waldman 1984, Kalirajan 1989, Battese, Coelli, and Colby 1989, Bravo-Ureta and Rieger 1990, Battese and Coelli 1992, 1995, Bakhshoodeh and Thomson 2001, Sharma, Pradhan, and Leung 2001, etc.). Our study differs from these previous agricultural empirical studies by integrating the water salinity as an input in the frontier production function.

The paper is organized as follows. The management of oases irrigation systems is presented in the next section. In the section after that, we describe the data. Then we specify the models and present the results of the estimation. Finally, in the last section we show the main implications of our results and conclude.

Management of Oasis Irrigation Systems

Irrigation in Tunisia is a very old practice, but it mostly developed after the country's independence. So, since the 1960s the State has fostered irrigated oases and set up numerous projects for the development and use of water in oases. Oases management is based on longstanding traditions. Water allocation, the spacing of the irrigation intervals, as well as the irrigation time are based on historic water rights and inherently tied to a particular plot of land. The oases in the Nefzaoua region can be broadly put into two categories, which are distinguished according to their managerial form. On the one hand, there are water user associations for individual oases which are called GIC oases. The second category is formed by private farmers.

In GIC oases, the irrigation network operates on rotational delivery, and an irrigation interval is imposed on each oasis depending on the served area. The water allocation is defined by the GIC according to the area of the farm. GIC members get water and allocate land based on a communal agreement upon the distribution of the resources. Furthermore, responsibility for the maintenance of the conveying system is handed over to the individual, as well as the periodic clearing of the drainage channels. The government financed the initial construction of oasis irrigation systems.

Irrigation management is undertaken by water user associations, with a government subsidy for the maintenance and operation of the main canal and drilling of wells. The majority of GICs have been facing diminished water supply and the problem of salinity.

Private farmers get irrigation water either from buying water quotas from abandoned perimeters or by drilling boreholes into the Complex Terminal aquifer. The Regional Department of Agricultural Development does not formally approve the drilling of private boreholes, nor in any way does it support farms that drill them—it considers them illegal. In Tunisia, groundwater is state-owned. Nowadays in the Nefzaoua region, the estimated total extraction of private wells (8000 l/s) exceeds the governmentally controlled pumped quantity (7000 l/s).

The main difference between the two systems is in water management. As they have their own boreholes, private farmers can apply water when needed. In contrast, GIC farmers get water according to the irrigation schedule. Without exception, all the farmers use the flood irrigation method on their fields.

Data

All this empirical work is based on two surveys carried out with the help of the Tunisian Ministry of Agriculture and a team of ETH Zurich (Swiss Federal Institute of Technology), conducted during two field campaigns (in autumn 2002 and autumn 2003).[1] Data were collected by random sampling of farmers from different areas in the Nefzaoua oases. The criteria for the selection of the oases to be sampled were discussed with representatives of the General Direction of Water Resources (GDWR) in Tunis and the Regional Department of Agricultural Development (RDAD) in Kebili. The inclusion of the study goals in the selection procedure ensured that oases affected by various levels of salinity were chosen.

A set of 13 irrigated oasis perimeters were chosen, of which 5 are managed by GICs. The GIC oases selected were Tifout, Glea, Souk Elbayez, Douz, and Hsay. The remaining 8 are owned by private farmers who are not served by GIC water but who are organized among themselves. The private oases selected were Blidet, Douz, Gemna, Golaa, Kalouamen, Kebili, Nouil, and Zaafrane. All these oases were selected for different levels of soil and salinity. The description of the different oases according to their degree of salinity is presented in Table 1. In general, the water salinity of private farms is lower than that of the GIC ones. Water salinity is lower on private farms because it is dynamic and most of the private farms are newly settled. This makes these farmers drill their wells in the zones where the aquifer is not affected by salinity. GIC oases have varying levels of salinity. Each oasis has the same level of salinity with no variation. GIC farmers of the same oasis have the same level of water salinity because they have the same source of irrigation water.

Farmers were randomly selected from each oasis and interviewed with a questionnaire. A representative sampling of farmers within each oasis had to be ensured. For this purpose, based on the data provided by the RDAD, the farmers of a certain GIC oasis were grouped into three different farm categories according to farm size. Farmers to be sampled within a certain category

Table 1. Description of Oases Surveyed per Degree of Salinity (g/l)

	Mean	Maximum	Minimum	Standard Deviation
GIC Oases				
Tifout	1.8	1.8	1.8	0
Glea	2.6	2.6	2.6	0
Souk Elbayez	3.6	3.6	3.6	0
Douz	4.2	4.2	4.2	0
Hsay	7	7	7	0
Private Oases				
Blidet	2	2	2	0
Golaa	2.57	3.2	2.5	0.20
Gemna	2.06	3	1	0.57
Kalouamen	2	2	2	2
Douz	3.28	4	2	0.62
Kebili	2.45	3	2	0.35
Nouil	1	1	1	0
Zaafrane	1.56	2	1.5	0.17

[1] The region is arid, and so from year to year the climate is the same, without appreciable differences. Date production does not vary enormously from one year to the next.

were then randomly chosen out of the total set of farmers of a particular oasis. The farmer, identified by drawing a number from a basket, was accepted for interviewing if the area of his farmland was within a 10 percent margin of the category to be sampled. During this process, 40 farmers of each oasis were selected. In the end, 138 GIC farmers were effectively interviewed. Such data were not available in the case of the private farmers. The 8 private oases were chosen randomly from the list of private oases, and a total of 144 private farmers were interviewed on the basis of the information given by the farmers themselves.

In total, 282 farmers[2] participated in the surveys, which included three types of data:

- General information about the families, particularly about, age, education, size, experience, number of days worked in agriculture, etc.
- Information about each plot of land. Data include size of plot, type of crop, type of labor contract used, production levels, and precise amounts of labor inputs as well as precise amounts of other inputs.
- Our interest was specially focused on the data concerning the quality of water, the quality of soil, and the timing and the frequency of irrigation.

Besides the household survey, information on various aspects of irrigation management (such as water distribution) was obtained from the GIC and administration authorities.

Stochastic Production Frontier and Technical Inefficiency Model

This paper focuses on the performance of the two oasis irrigation systems in Nefzaoua (GIC and private systems) in terms of technical efficiency. The level and variation of data production are explained in terms of five inputs, namely, irrigated water (X_1), labor (X_2), phosphate (X_3), farmyard manure (X_4), and water salinity (X_5). The description of output and input variables is presented in Table 2, and their summary statistics are presented in Table 3. Tables 2 and 3 present also various farm-specific variables included in the technical inefficiency model to determine their influence on technical efficiency in date production. Output and inputs are expressed in per palm tree terms for several reasons. Because of limited scope for the number of palm trees, increased production has to come from increases in crop yields or output per palm tree. Thus it is appropriate to estimate production frontier on a per palm tree basis. Furthermore, crop yields have been widely used in assessing the performance of irrigation systems.

When the irrigation systems are compared in terms of relative technical efficiency, it is important to use a single common frontier technology for the two systems. In view of the close geographical proximity, fairly similar biophysical factors, and the more or less equal access to production technologies, it seems reasonable to assume a common date production frontier for the two irrigation systems involved in this study. However, the system-specific frontier would be more appropriate to examine spatial differences in technical efficiency within the system. Consequently, both common and system-specific production frontiers are estimated, by applying the Battese and Coelli (1995) model.[3]

The Battese and Coelli (1995) Model

Given the inherently stochastic nature of date production, the stochastic frontier production function approach is preferred to assess the technical efficiency of date farmers in the Nefzaoua oases. The Battese and Coelli (1995) model for the cross-sectional data is defined in two equations as

$$(1) \qquad Y_i = f(X_i;\beta)\exp(V_i - U_i),$$

where Y_i denotes the production of the ith farmer in the sample ($i = 1, 2, \ldots, n$), X_i is a $(1\times k)$ vector of input quantities used by the ith farmer, β is a $(k\times 1)$ vector of parameters to be estimated, $f(X_i;\beta)$ is an appropriate parametric form for the

[2] For the private sample, we interviewed 144 farmers, of whom 10 had young farms that are not productive. Therefore we treated only 134 questionnaires.

[3] Common frontier means the frontier for all the farms (private and GIC ones together). Private-specific frontier means a frontier for only private farms. GIC-specific frontier means a frontier for only GIC farms.

Table 2. Description of Output, Input, and Farm-Specific Variables

Variable Name	Description
Output (Y)	Amount of date production, kg/palm tree
Input variables	
Irrigated water (X_1)	Amount of water applied, m^3/palm tree
Labor (X_2)	Amount of hired and family labor, number of days/year/palm tree
Phosphate (X_3)	Amount of phosphate used, kg/palm tree
Farmyard manure (X_4)	Amount of farmyard manure applied, tons/palm tree
Water salinity (X_5)	Salinity of irrigated water (g/l)
Farm-Specific Variables	
Farmer's age (Z_1)	Age, number of years
Farmer's education dummy (Z_2)	Value 1 if the number of years of education is below 7, 0 otherwise
Farmer's experience (Z_3)	Farmer's experience, number of years
Land fragmentation (Z_4)	Total number of parcels irrigated
Farm size (Z_5)	Total farm size, in ares [a]
Soil quality dummy (Z_6)	Value 1 if soil type is fine, 0 otherwise
Farmer's family size (Z_7)	Number of member of household
System dummy (Z_8)	Value 1 if the farm is private, 0 if GIC

[a] One acre is equal to 40.4685 ares.

Table 3. Summary Statistics of Output, Input, and Farm-Specific Variables

	Mean	Minimum	Maximum	Standard Deviation
Output (Y)	31.344	2.377	102	18.039
Input variables				
X_1	304.739	12	3801.583	362.139
X_2	2.726	0	39	3.040
X_3	1.663	0	15	2.191
X_4	0.060	0	0.6	0.066
X_5	3.218	1	7	1.648
Farm-Specific Variables				
Z_1	57.411	21	100	14.529
Z_2	0.746	0	1	0.435
Z_3	22.665	1	70	13.870
Z_4	1.650	1	22	1.667
Z_5	147.474	0.15	7000	443.787
Z_6	0.669	0	1	0.471
Z_7	7.088	1	23	2.878
Z_8	0.492	0	1	0.500

underlying technology, V_i are assumed to be independently and identically distributed $N(0,\sigma_v^2)$ random errors, independent of U_i, and U_i are non-negative random variables, associated with technical inefficiency in production, which are assumed to be independently distributed with truncations (at zero) of the normal distribution with mean, μ_i, and variance, $\sigma_u^2 [N(\mu_i, \sigma_u^2)]$. Under these assumptions the mean of technical inefficiency effects, μ_i, can more formally be expressed as follows:

(2) $$\mu_i = Z_i \delta,$$

where Z is a $(1 \times m)$ vector of observable farm-specific variables hypothesized to be associated with technical inefficiency, and δ is an $(m \times 1)$ vector of unknown parameters to be estimated. The technical efficiency of the ith sample farm, denoted by TE_i, is defined in terms of the ratio of the observed output to the corresponding frontier output, conditional on the levels of inputs used by that farmer. It is given as

(3) $$TE_i = \exp(-U_i) = Y_i / f(X_i; \beta) \exp(V_i),$$

where $f(X_i;\beta)\exp(V_i)$ is the stochastic frontier production. The prediction of technical efficiencies is based on the conditional expectation in expression (3), given the model specifications (Battese and Coelli 1988).

In recent years the Battese and Coelli (1995) model for the technical inefficiency effects has become popular thanks to its computational simplicity as well as its ability to examine the effects of various farm-specific variables on technical efficiency in an econometrically consistent manner, as opposed to a traditional two-step procedure, which is inconsistent with the assumption of independently and identically distributed technical inefficiency effects in the stochastic frontier. The main advantage of this technique over the two-stage technique is that it incorporates farm-specific factors in the estimation of the production frontier because these factors may have a direct impact on efficiency.

On the basis of the generalized likelihood ratio test, given the specification of the translog, the Cobb-Douglas form is found to be an adequate representation of the used data.[4] Although the Cobb-Douglas specification is restrictive, it provides an adequate representation of production, as interest lies on efficiency measurement and not on analysis of production structure.[5] The model estimated for the common sample[6] is specified as

$$\ln Y_i = \beta_0 + \sum \beta_k X_{ki} + V_i - U_i, \quad (4)$$

where subscript i refers to the ith farmer in the sample, ln represents the natural logarithm, Y is the output variable and X are input variables [irrigated water (X_1), labor (X_2), phosphate (X_3), farmyard manure (X_4), and water salinity (X_5)], as defined in Table 2, β_k are parameters to be estimated, and V_i and U_i are the random variables.

Following Battese and Coelli (1995), the mean of technical inefficiency effects, μ_i, is further defined as

$$\mu_i = \delta_0 + \sum \delta_k Z_{ik}, \quad (5)$$

where Z are farm-specific variables defined in Table 3 and δ_k are unknown parameters to be estimated. The Z variables included in the model of technical inefficiency are socioeconomic factors (age, education, farmer's family size, experience, farm size, number of parcels or land fragmentation), with a system dummy in only common model 2. Since the dependent variable in (5) is defined in terms of technical inefficiency, it should be noted that a farm-specific variable associated with the negative (positive) coefficient would have a positive (negative) effect on technical efficiency.

The parameters (β_k) for the stochastic production frontier model and those for the technical inefficiency model (δ_k) are estimated simultaneously by the maximum likelihood method using the FRONTIER version 4.1 program (see Coelli 1996). This program estimates the variance parameters of the likelihood function in terms of $\sigma^2 = \sigma_u^2 + \sigma_v^2$ and $\gamma = \sigma_u^2/\sigma^2$. The parameter γ can determine whether a stochastic frontier is warranted as opposed to an average (OLS) function. The rejection of the null hypothesis, $H_0: \gamma = 0$, implies the existence of a stochastic production frontier.

The technical inefficiency model can be estimated only if the technical inefficiency effects, U_i, are stochastic and have particular distributional properties (Battese and Coelli 1995). Therefore, it is of interest to test various null hypotheses such as the following: (i) technical inefficiency effects are not stochastic, $H_0: \gamma = 0$; (ii) technical inefficiency effects are absent from the production function model, $H_0: \gamma = \delta_0 = \delta_1 = \delta_2 = \ldots = \delta_7 = 0$; (iii) technical inefficiency effects follow a half-normal distribution, originally suggested by Aigner, Lovell, and Schmidt (1977), $H_0: \delta_0 = \delta_1 = \delta_2 = \ldots = \delta_7 = 0$; (iv) farm-specific factors included in the technical inefficiency model have no effect on the level of technical inefficiencies of date production, or, equivalently, technical inefficiencies follow a standard truncated-normal distribution, suggested by Stevenson (1980), $H_0: \delta_1 = \delta_2 = \ldots = \delta_7 = 0$; and (v) the

[4] The simpler form of the Cobb-Douglas function is tested for adequacy as the functional by setting the coefficients of second-order terms in the translog model equal to zero. The test statistics are equal to 21.47 for a common model with no system dummy (model 1) and 22.10 for the common model with system dummy (model 2). All these values are compared to 24.99, the 95 percent critical value for the chi-squared distribution with degrees of freedom equal to 15.

[5] Several studies (Koop and Smith 1980, Ahmad and Bravo-Ureta 1996) have used the Cobb-Douglas functional form to analyze farm efficiency despite its well-known limitations. They found that technical efficiency measures do not appear to be affected by the choice of the functional form.

[6] Common sample means the total sample for all farms (private and GIC ones).

system dummy variable is not significant, H_0: $\delta_8 = 0$. Under H_0 : $\gamma = 0$, the stochastic frontier model reduces to a traditional average response function in which the explanatory variables in the technical inefficiency model are also included in the production function. These and other relevant null hypotheses can be tested using the generalized likelihood ratio statistic, λ, given by

(6) $$\lambda = -2\{\ln (L(H_0)) - \ln (L(H_1))\},$$

where $L(H_0)$ and $L(H_1)$ denote the values of likelihood function under the null (H_0) and alternative (H_1) hypotheses, respectively. If the given null hypothesis is true, λ has approximately chi-square distribution or mixed chi-square distribution when the null hypothesis involves $\gamma = 0$ (Coelli 1995).

Interpretation of Empirical Results

The findings from the application of the stochastic frontier production function models present a number of noteworthy features of the performance of the date producers in relation to their specific characteristics. The common stochastic production frontier model [(4) and (5)] is estimated under two different specifications. The two specifications are similar except that model 2 contains the system dummy in the technical inefficiency model, while model 1 does not. We introduce the system dummy variable in model 2 to test the effect of irrigation management on technical efficiency in date production. This system dummy variable represents the form of organization (GIC or private). Although both common models are presented in Table 4, the subsequent discussion on parameter estimates, tests of hypotheses, and intersystem comparison of technical efficiency is based on model 1. Besides the two common frontier models, the system-specific frontier models are also estimated for each system to examine the intra-system differences in technical efficiencies. Maximum likelihood estimates and tests of hypotheses pertaining to the specific frontier models are not presented.

The main results derived from this study are summarized as follows. The maximum likelihood estimates for the common stochastic production frontier models and those for the technical inefficiency model are presented in Table 4. Except for the water salinity, all slope coefficients of the stochastic frontier represent output elasticities of all inputs. The signs of the parameters are as expected. Except for the farmyard manure, output estimates for all inputs are significant at the 0.01 level. The estimate of output elasticity of date production with respect to irrigation water is significant and its value is 0.223. An increase of 10 percent in irrigation water can increase the date production by 2.23 percent. The phosphate coefficient is statistically significant; however, the fertilizer farmyard manure has a positive elasticity but is not significant. In view of surplus labor in agriculture, the significant estimate of output elasticity for labor is expected. The coefficient associated with the degree of salinity of water is of particular interest. It is negative and significant at only 0.01 levels. The negative coefficient implies that irrigation water salinity has a negative impact on date production. It indicates that date yield decreases with increasing irrigation water salinity.

Both magnitude (0.857) and significance ($P <$ 0.01) of the variance parameter, γ, suggest that the technical inefficiency effects make a significant contribution to the variability of date yields for farmers in Nefzaoua oases. Thus the traditional average (OLS) production function, with no technical inefficiency effects, is not an adequate representation of date farmers involved in this study. Generalized likelihood ratio tests of various null hypotheses involving the restrictions on the variance parameter, γ, in the stochastic production frontier and the δ coefficients in the technical inefficiency model are presented in Table 5. The first and second null hypotheses that the technical inefficiency effects are not stochastic and that technical inefficiency effects are absent are rejected. Given the assumptions associated with the stochastic frontier with the model for technical inefficiency effects, the rejection of the third null hypothesis suggests that the standard stochastic error component model is also not appropriate for half-normal distribution of the technical inefficiency effects. However, the acceptance of the fourth null hypothesis implies that the standard stochastic error component model can be appropriate for truncated normal distribution of the technical inefficiency effects.

The result of the fourth null hypothesis indicates also that farm-specific variables included in the technical inefficiency model do not contribute

Table 4. Maximum Likelihood Estimates of the Common Stochastic Production Frontier and Technical Inefficiency Model

		Model 1		Model 2	
	Parameters	Coefficients	t-ratios	Coefficients	t-ratios
Stochastic Frontier Models					
Constant	β_0	3.476	10.86	3.475	10.89
ln (irrigated water)	β_1	0.223	4.51	0.223	4.47
ln (labor)	β_2	0.091	2.09	0.092	2.05
ln (phosphate)	β_3	0.052	3.91	0.051	3.88
ln (farmyard manure)	β_4	0.004	0.106	0.005	0.125
Water salinity	β_5	-0.111	-6.16	-0.112	-5.92
Inefficiency Models					
Constant	δ_0	-0.542	-0.958	-0.469	-0.753
Farmer's age (Z_1)	δ_1	-0.005	-0.648	-0.005	-0.684
Education dummy (Z_2)	δ_2	0.179	0.824	0.695	0.16
Farmer's experience (Z_3)	δ_3	0.013	1.501	0.013	1.421
Parceling (Z_4)	δ_4	-0.024	-0.300	-0.022	-0.264
Farm size (Z_5)	δ_5	-0.0007	-0.889	-0.0007	-0.866
Soil quality dummy (Z_6)	δ_6	0.171	0.848	0.156	0.761
Farmer's family size (Z_7)	δ_7	0.014	0.471	0.012	0.415
System dummy (Z_8)	δ_8	--	--	0.042	0.143
Variance parameters	σ^2	0.534	4.554	0.517	4.137
	γ	0.857	15.12	0.850	14.358
ln (likelihood)		-163.614		-163.703	

Table 5. Generalized Likelihood Ratio Tests for the Common Frontier Model 1

Null Hypothesis (H_0)[a]	Log Likelihood Value	Test Statistic (λ)	Critical Value ($X^2_{0.95}$)	Decision
$\gamma = 0$	-181.120	20.03	5.138	Reject H_0
$\gamma = \delta_0 = \delta_1 = \ldots = \delta_7 = 0$	-181.120	35.01	16.274	Reject H_0
$\delta_0 = \delta_1 = \delta_2 = \ldots = \delta_7 = 0$	-171.104	15.572	15.507	Reject H_0
$\delta_1 = \delta_2 = \ldots = \delta_7 = 0$	-165.566	3.904	14.067	Accept H_0
$\delta_8 = 0$	-163.614	0.178	3.841	Accept H_0

[a] The critical values for the first and second null hypotheses involving $\gamma = 0$ are obtained from Kodde and Palm (1986, Table 1, p. 1246), with degrees of freedom equal to 2 for the first hypothesis and degrees of freedom equal to 9 for the second hypothesis.

significantly, as a group, to the explanation of the technical inefficiencies in date production. Also, on the basis of asymptotic *t* ratios, all farm-specific factors are insignificant. From these results we might conclude that technical inefficiency effects are due to factors outside the control of the farmers, such as environmental degradation and irrigation intervals. The coefficient (δ_8) associated with the system dummy in the technical inefficiency model in the common frontier (model 2) is positive but insignificant on the basis of both asymptotic *t* ratio and log likelihood ratio tests. From this result we cannot conclude which system is more technically efficient.

Technical Efficiency Estimates

As indicated, to determine the impact of some management factors on irrigation allocation, technical efficiency could be used as a measure of management capability, and thus as an index of sustainability. Given that there are differences in efficiency levels among date farmers in the two irrigation systems, it is appropriate to question why some farmers can achieve relatively high efficiency while others are technically less efficient. Variations in the technical efficiencies of farmers may arise from farm characteristics that affect the ability of the farmer to use the existing technology adequately.

All the frequency distributions of technical efficiency measures are summarized in Table 6. The mean value of technical efficiency for all farms of the two systems is estimated to be 0.683, with a range from 0.114 to 0.941. It indicates that output can be increased on average by 31.7 percent with the present state of technology and the same amount of inputs as before if the technical inefficiencies are removed completely. Half of the farmers are under 72.35 percent efficient. Statistics indicate also that half of the farmers (136) have an efficiency level between 60 percent and 80 percent. About one-quarter of the farmers (25.74 percent) are at an inefficiency level of 80 percent or above, and 16 farms below 40 percent. Thus, there is considerable room for improvement in the technical efficiencies of date farmers in Nefzaoua oases.

In summary, these statistics are quite comparable to those reported by previous frontier studies in agriculture in developing countries. For example, the overall average level of technical efficiency computed from all the studies presented by Thiam, Bravo-Ureta, and Rivas (2001) is 68 percent. The parametric studies relying on the Cobb-Douglas form reported technical efficiency measures ranging from 52 percent to 84 percent, with an average of 71 percent.

On the basis of both common and system-specific frontiers, the communal form of management appears technically little less efficient than private management. On average, technical efficiency levels in date production were a little lower for GIC systems than for private ones. For example, the mean technical efficiencies for the GIC farmers were 67.29 percent based on the common frontier and 67.88 percent based on their specific frontier. The corresponding values for the private farmers are 69.49 percent and 69.99 percent, respectively. Also, in terms of standard deviations, technical efficiency estimates show a lower degree of variability under the private system than under the GIC one. This might be related to various factors. First, private farmers profit from economies of scale. Because many of them are young farmers, their plot sizes have not become affected by continuous inheritance parting. Their generally better monetary situation allows those farmers to better substitute scarce input factors with capital. Second, the salinity of irrigation water, which is outside the control of the farmers, might have a negative effect on their technical efficiencies. GIC farmers are more affected by water salinity than private ones.

Policy Implications

Agricultural policy in Tunisia is largely determined by considerations of food security, self-sufficiency, and import-substitution practices. Apart from tourism, agriculture provides the main source of income for the inhabitants of the Tunisian oases. Government is satisfying the growing demand for food by over-pumping groundwater resources.

The empirical estimates of technical efficiency in irrigated agriculture have proved to be useful. Naturally, for the water resources manager in the semi-arid and arid zones, it is interesting to know how far agricultural production can be expected to increase its output by simply increasing its productive efficiency, without absorbing further resources, given the level of technology involved. The econometric estimation of the farm-level technical inefficiencies in agricultural production reveals that the farmers in the Nefzaoua oases produce well below their potential agricultural output. It has been estimated that, for the same amounts of inputs, output could be increased by up to 33 percent in the GIC system and 31 percent in the private one. The results indicate that there is a considerable potential for improving household income by improving productive efficiency. Maximum efficient benefits and potential

Table 6. Frequency Distributions of Technical Efficiency Estimates

Efficiency Index (%)	GIC sample	Private sample	Common sample
< 40	11 (7.97)	5 (3.73)	16 (5.88)
40–60	26 (18.84)	24 (17.91)	50 (18.38)
60–80	63 (45.65)	73 (54.48)	136 (50)
80–100	38 (27.54)	32 (23.88)	70 (25.74)
Mean	67.29 (67.88)	69.49 (69.99)	68.38
Median	70.22 (71.25)	73.68 (73.99)	72.35
Maximum	92.32 (93.46)	94.11 (96.54)	94.11
Minimum	11.47 (9.60)	21.07 (20.53)	11.47
Standard deviation	17.99 (17.82)	14.16 (15.93)	16.23
Observations	138	134	272

Note: Figures in parentheses are the corresponding measures from the system-specific stochastic frontiers.

benefit increases at full efficiency levels are presented in Table 7 for the two systems.[7] By reaching full efficiency levels, GIC farmers would be able to increase their actual benefits by 71 percent; however, private farmers would be able to increase their actual benefits only by 39 percent. For all Nefzaoua oases, farmers would be able to increase their actual benefits by 43 percent. Based on these results, the two farming systems are shown to provide increased local economic benefits, which would promote local rural development.

Benefits from GIC farms seem to be very low compared with private ones, for many reasons: the low palm tree yield of GIC oases; the low price of dates, which is related to the quality of date, affected by water salinity; and the lower size of GIC farms.[8] When property in the oasis passes from one generation to the next, the size of the farms is fragmented until it sometimes becomes economically unfeasible to use them. The farmers then look for other alternative employment and desert the oasis.

While the private farms are shown to yield more economic benefits than the GIC ones, this doesn't tell a policymaker that they should be preferred. These benefits have to be balanced against any environmental costs or benefits by size. Water salinity, which reduces the quantity and quality of date production, affects mostly GIC farmers. Besides, private farmers profit from economies of scale. Private farms are larger than GIC ones. Farm policy that leads to more diversified and smaller scale farming is necessary if oases are to more effectively contribute to long-term rural community development and vitality.

Understanding the differences between farming systems can help policymakers and advocates define and guide policy in response to societal goals. For example, if rural development is a goal, policies and programs can be targeted to those types of farms that provide the most benefits to the community. Improved performance could be a rationale for rural economic development programs. Keeping more money in the community might be desirable as it would have the effect of maintaining or strengthening local economic health and resiliency.

If these results are a close depiction of reality, it would mean that policies aiming at increasing technical efficiency levels by Nefzaoua farmers could help to minimize the overexploitation of

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[7] Observed benefits are measured by using the ordinary profit function,

$$\Pi_{obs} = pY - \sum_{i=1}^{4} w_i X_i ,$$

where Y is the date production, p is its price, X_1, X_2, X_3, and X_4 are inputs which represent, respectively, irrigated water, labor, phosphate, and farmyard manure, and w_1, w_2, w_3, and w_4 are the input prices. Fixed inputs are not considered. Maximum potential benefits are measured at full efficiency levels,

$$\Pi_{\max} = pY(1+TI) - \sum_{i=1}^{4} w_i X_i ,$$

where TI is the technical inefficiency. $Y(1+TI)$ is the potential output of date production.

[8] The total area of GIC oases (12,256 ares) considered in the sample is lower than that of private oases (28,739 ares).

Table 7. Various Benefit Levels for the Two Systems

Systems	Observed Benefit Levels	Potential Benefit Levels at Full Efficiency Level	Potential Benefit Increases at Full Efficiency Levels
GIC system	65771	112655	46884 (71.28%)
Private system	423450	588918	165468 (39.07%)
Common system	489221	701573	212352 (43.4%)

Note: These values are expressed in Tunisian dinars (TD). One U.S. dollar equals approximately DT 1.311. One euro equals approximately DT 1.6.

groundwater resources. If Nefzaoua oases are to be preserved by the government over the long run, they could be sustained with this infinite resource, and the capital saved by pursuing intelligent groundwater management strategies could be used to invest in water-economic irrigation systems such as PVC piping and in education programs.

Conclusion

This paper investigates technical efficiency measures derived from two samples of private and GIC farms in Southern Tunisia using stochastic production frontier (SPF) models. The proposed parametric approach framework provides some evidence of substantial inefficiencies in both systems. On average, the private system is found to be slightly more efficient than the GIC one. We find that date yield could be explained mainly by four variables: water quantity applied per palm tree, labor per palm tree, phosphate per palm tree, and water salinity. Output elasticities of all inputs are found to be positive and significant except for the farmyard manure. Water salinity has a considerable negative impact on date productivity. For the technical inefficiency model, none of the socioeconomic variables seem to matter. This result is due to the lack of variability in these variables. The majority of the farmers have the same characteristics.

From a policy standpoint, more accurate technical efficiency estimates are crucial in guiding policy decisions dealing with farm extension and training programs, among others. The results reveal significant technical inefficiencies for the sample date producers of the two systems. Relative both to the common and specific frontier models, on average, GIC farmers are found to be technically a little less efficient than private farmers. For example, the mean technical efficiency levels for the GIC oases are 0.672 based on the common frontier and 0.678 based on their specific frontier. The corresponding values for the private oases are 0.694 based on the common frontier and 0.699 based on their specific frontier. Moreover, the technical efficiency estimates show a significantly higher variability in the GIC oases. Normally, the GIC system must be more technically efficient and more equitable in terms of distribution of water and distribution of productivity gains, but in reality this is not the case because the farmers of this system are more affected by water salinity and the length of irrigation interval, which exerts water stress on the crops. However, the differences between measures of technical efficiencies of the two systems are very small. These results are confirmed by the non-significance of the estimated coefficient of the system dummy included in model 2.

Since private farmers are not more efficient than GIC ones and their borehole drilling and pumping activity are not monitored and are uncontrolled, a further promotion of the unregulated private groundwater utilization should be discouraged within the present legal framework. Due to the invisible nature of the groundwater resource, GIC farmers, whose use of water is controlled by local water administration, are better able to secure the productive potential of groundwater and soil salinization than a large number of private farmers, whose use of water is uncontrolled. In this case, in the process of flourishing, oases farms will contribute to the strengthening of society, providing rural communities with opportunities for self-employment and ownership of land, and providing a cultural and traditional way of life as well as nurturing places in which to raise families.

The local threat of salinization as well as the increasing depth from which groundwater has to be pumped are the two major restrictions with regard to future groundwater management options. The increasing demand therefore has to be covered by intelligent strategies. Options of demand management have not been investigated in this study. Over the course of time, farmers adapt to changing environmental as well as economic conditions. Hence, the demand sensitivity of irrigation water to its price might be utilized by decision makers to steer future agriculture production towards a desired direction. The economic system of desert agriculture could be modeled by means of a decentralized agent approach with endogenous demand. The evolving patterns of groundwater utilization under optimizing behavior could then be studied. Further studies to investigate sources of inefficiency and compare the two systems, such as the determination of allocative and economic inefficiencies, are recommended.

References

Ahmad, M., and B. Bravo-Ureta. 1996. "Technical Efficiency Measures for Dairy Farms Using Panel Data: A Comparison of Alternative Model Specifications." *Journal of Productivity Analysis* 7(4): 399–416.

Aigner, D.J., C.A.K. Lovell, and P. Schmidt. 1977. "Formulation and Estimation of Stochastic Frontier Production Models." *Journal of Econometrics* 6(1): 21–37.

Bagi, F.S., and C.J. Huang. 1983. "Estimation Production Technical Efficiency for Individual Farms in Tennessee." *Canadian Journal of Agricultural Economics* 31(2): 249–256.

Bakhshoodeh, M., and K.J. Thomson. 2001. "Input and Output Technical Efficiencies of Wheat Production in Kerman, Iran." *Agricultural Economics* 24(3): 307–313.

Battese, G.E., and T.J. Coelli. 1988. "Prediction of Firm-Level Technical Efficiencies with a Generalized Frontier Production Function and Panel Data." *Journal of Econometrics* 38(3): 387–399.

____. 1992. "Frontier Production Functions, Technical Efficiency Effects and Panel Data: With Application to Paddy Farmers in India." *Journal of Productivity Analysis* 3(1/2): 153–169.

____. 1995. "A Model for Technical Inefficiency Effects in Frontier Production Function for Panel Data." *Empirical Economics* 20(2): 325–338.

Battese, G.E., T.J. Coelli, and T.C. Colby. 1989. "Estimation of Frontier Production Functions and the Efficiencies of Indian Farms Using Panel Data from ICRISAT's Village Level Studies." *Journal of Quantitative Economics* 5(2): 327–348.

Battese, G.E., and G.S. Corra. 1977. "Estimation of a Production Frontier Model: With Application to the Pastoral Zone of Eastern Australia." *Australian Journal of Agricultural Economics* 21(3): 169–179.

Bravo-Ureta, B.E., and L. Rieger. 1990. "Alternative Production Frontier Methodologies and Dairy Farm Efficiencies." *Journal of Agricultural Economics* 41(2): 215–226.

Chiang, W.H., and W. Kinzelbach. 2001. *3D-Groundwater Modeling with PMWIN: A Simulation System for Modeling Groundwater Flow and Pollution*. Berlin: Springer.

Coelli, T. 1995. "Recent Developments in Frontier Modeling and Efficiency Measurement." *Australian Journal of Agricultural Economics* 39(3): 219–245.

____. 1996. "A Guide to FRONTIER Version 4.1 : A Computer Program for Stochastic Frontier Production and Cost Function Estimation." CEPA Working Paper No. 96/07. Centre for Efficiency and Productivity Analysis, University of New England, Armidale, New South Wales, Australia.

Food and Agriculture Organization (FAO). 2004. *Agricultural Statistical Database*. Food and Agricultural Organization of the United Nations, Rome.

Huang, C.J., and F.S. Bagi. 1984. "Technical Efficiency on Individual Farms in Northwest India." *Southern Economic Journal* 51(1): 108–115.

Jondrow, J., C.A.K. Lovell, I.S. Materov, and P. Schmidt. 1982. "On the Estimation of Technical Inefficiency in the Stochastic Frontier Production Function Model." *Journal of Econometrics* 19(2/3): 233–238.

Kalirajan, K. 1981. "An Econometric Analysis of Yield Variability in Paddy Production." *Canadian Journal of Agricultural Economics* 29(2): 283–294.

____. 1982. "On Measuring Yield Potential of the High Yielding Varieties Technology at Farm Level." *Journal of Agricultural Economics* 33(2): 227–235.

____. 1989. "On Measuring the Contribution of Human Capital to Agricultural Production." *Indian Economic Review* 24(2): 247–261.

Kalirajan, K., and J.C. Flinn. 1983. "The Measurement of Farm-Specific Technical Efficiency." *Pakistan Journal of Applied Economics* 2: 167–180.

Kassah, A. 1996. "Les Oasis Tunisiennes: Aménagement Hydro Agricole et Développement en Zone Aride." *Série Géographique* (No. 13), Centre d'Études et de Recherches Economiques et Sociales, Tunis.

Kodde, D.A., and F.C. Palm. 1986. "Wald Criteria for Jointly Testing Equality and Inequality Restrictions." *Econometrica* 54(5): 1243–1248.

Koop, R.J., and V.K. Smith. 1980. "Frontier Production Function Estimates for Steam Electric Generation: A Comparative Analysis." *Southern Economic Journal* 47(1): 1049–1059.

Kriaa, S. 2003. "Contribution à l'Étude de la Qualité des Eaux de la Nappe du Complexe Terminal dans la Nefzaoua." Master's thesis, École Nationale d'Ingénieur de Tunis, Tunis.

Lee, L.F., and W.G. Tyler. 1978. "A Stochastic Frontier Production Function and Average Efficiency : An Empirical Analysis." *Journal of Econometrics* 7(3): 385–389.

Mamou, A., and A. Hlaimi. 1999. "Les Nappes Phréatiques de la Nefzaoua: Caractéristique et Exploitation." Direction Générale des Ressources en Eaux, Tunis.

Mamou, A., and A. Kassah. 2002. "Eau et Développement dans le Sud Tunisien." *Série Géographique* (No. 23), Centre d'Études et de Recherches Economiques et Sociales, Tunis.

Observatory of the Sahara and the Sahel (OSS). 2003. "The North Western Sahara Aquifer System: Joint Management of a Transborder Basin." Technical report, OSS, Tunis.

Pitt, M.M., and L.F. Lee. 1981. "Measurement and Sources of Technical Inefficiency in the Indonesian Weaving Industry." *Journal of Development Economics* 9(1): 43–64.

Schmidt, P., and R. Sickles. 1984. "Production Frontiers and Panel Data." *Journal of Business Economics and Statistics* 2(4): 367–374.

Sharma, K.R., N.C. Pradhan, and P. Leung. 2001. "Stochastic Frontier Approach to Measuring Irrigation Performance: An Application to Rice Production Under the Two Systems in the Tarai of Nepal." *Water Resources Research* 37(7): 2009–2018.

Stevenson, R.F. 1980. "Likelihood Functions for Generalized Stochastic Frontier Estimation." *Journal of Econometrics* 13(1): 57–66.

Thiam, A., B.E. Bravo-Ureta, and T.E. Rivas. 2001. "Technical Efficiency in Developing Country Agriculture: A Meta-Analysis." *Agricultural Economics* 25(2/3): 235–243.

Waldman, D.M. 1984. "Properties of Technical Efficiency Estimators in the Stochastic Frontier Model." *Journal of Econometrics* 25(3): 353–364.