Date yield and water productivity in Nefzaoua Oases of Tunisia: a comparative analysis

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Abstract

The objective of this paper is to understand farm-level date yield variations, to estimate the impact of various inputs on date yields of farms, and to estimate the effects of farm-specific socioeconomic factors and environmental factors on irrigation water productivity in Nefzaoua Oases. The effect of water salinity on date yields is of particular interest. For this purpose data from two samples of 138 Water Users Associations farmers and 134 private ones were respectively collected in 2002 and 2003. Analysis of results showed that water productivity of irrigation is quite low in both systems.

Résumé

Le but de cet article est de comprendre les variations de la productivité des palmiers dattiers au niveau de l'exploitation et d'estimer les effets des facteurs socio-économiques et environnementaux sur le rendement de l'eau dans les oasis de Nefzaoua. L'effet de la salinité de l'eau sur la productivité des palmiers dattiers est de grand intérêt. Voilà pourquoi on a collecté les données à partir de deux échantillons respectivement de 138 agriculteurs des Associations des Usagés de l'Eau et de 134 exploitants privés en 2002 et 2003. L'analyse des résultats a montré que la productivité de l'eau d'irrigation est plutôt modeste dans les deux systèmes.

1. Introduction

Since independence, Tunisia has seen political stability. It has pursued a strategy of equitable development and has registered steady long-term development progress. From 1970 to 2001, real per capita income grew from 700$ to 2070$, while poverty declined from 40% to 10% for Tunisia's 2001 population of 9.7 million (World Bank, 2002). The contribution of agriculture to GDP was 12.5% in 2003 (INS, 2004). In the last fifty years, agricultural policy has been largely determined by considerations of food security and self-sufficiency. The irrigated area passed from 120 thousands ha in 1970 to around 400 thousands ha in 2002. Despite the irrigated area represents only 7% of the total agricultural area, the irrigated sector contributes by 32% to the total agricultural production, 20% to agricultural exports and by 26% to employment in agriculture (Ministry of Agriculture, Ninth Plan of Development 1997-2001).

Nefzaoua Oases will continue to be important sources of date production in the South of Tunisia, contributing 45% of the total area under date production and more than 55% of total date production each year. The Nefzaoua Oases region is famous for the production of high-quality Deglet Nour date. At the turn of the century, Tunisia was selling more than 20,000 metric tons in the world market which accounted for more than half of the total dates export of Africa or 10% of the total Tunisian agricultural export market value (FAO, 2004). Date production in Tunisian 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 increased from 58,800 tons in 1975-1976 to 107,000 in 2001-2002.

The source of irrigation in this entire region is the extracted water from the North-West Sahara Aquifer System (NWSAS). This 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 a total area of more than 10^6 km^2 This resource is shared by three countries: Algeria, Tunisia and Libya. The bulk of the water pumped from the system is utilized for the irrigation of approximately 14,000 km^2 of agricultural land. The present situation can be characterized as fossil groundwater mining, the total abstraction being 80 m^3/s. While the stored amount of water would be able to sustain this abstraction for another 10,000 years, the water comes at a price. On one hand, there is the cost of pumping and the investment for wells and pipelines. On the other, the cones of depression created by the pumping lead to a deterioration of the water quality due to the attraction of saline waters from different sources such as the brine of the Chotts, the saline water of the underlying Turonian and the seawater of the Mediterranean.

Besides the global management task for the whole basin, a number of sub-problems on a more local scale arises. For that purpose, the Nefzaoua Oases region is studied. Over the last fifty years, the pumped quantity in the Nefzaoua has increased six-fold while the irrigated area tripled. Over the last 50 years governmentally-induced expansion of irrigated agriculture as well as uncoordinated growth of private farming activity have induced a considerable overexploitation of the fossil groundwater basins. In the vicinity of Nefzaoua, the change in the hydraulic regime caused local deterioration of pumped water quality. Consequently, salinity of pumped water has risen up to 8g/l in certain areas thus rendering this water no longer suitable for irrigation pur-

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poses. The major problems created by water of poor quality are salinity, sodicity and ion toxicity. Through increased use of groundwater, salts accumulate in the root zone, adversely affecting the growth and yield of date.

The main objective of this paper is to understand farm-level date yield variations, to determine the sensibility of farmer's date yields to inputs (quantity of water applied, labour, farmyard manure, phosphate, and water salinity) and to estimate the effects of farm-specific socioeconomic factors and environmental factors on irrigation water productivities in Nefzaoua Oases. Specific objectives are to:

- Analyze inter- and intra-system variations in date yields in private and GIC systems of Nefzaoua Oases;
- Analyze factors contributing to such variations; and,
- Identify factors that affect water productivity.

The results presented here could be useful in considering future policies for enhancing date productivity through improved irrigation management. It will be particularly relevant in addressing numerous questions facing irrigation managers, such as the following: (1) which of the inputs should be more sensible in increasing date yields? (2) what is the impact of salinity on date yield? (3) which of the farmer's factors should affect irrigation water productivity?

The paper was organized as follows. Section 2 reports the study region. The data and irrigation management systems are presented in section 3. In section 4 we present the variations in date yields. In section 5 the models and their results of estimation are investigated. Finally, section 6 reports the conclusions and the policy implications of the results.

2. Study Region

2.1. Geography and Hydrogeology of the Nefzaoua Region

The Nefzaoua Region is situated in the southwest of Tunisia. It is limited to the north by the Governorate of Gafsa and Chott Fedjej, to the West by Chott El Jerid and Algeria, to the south by the Governorate of Tataouin and to the east by the Governorates of Tataouin, Medenin and Gabes. It covers an area of 22,454 km^2 mostly in the desert; the population living in this region is estimated to be about 131,000 inhabitants. Nefzaoua lies under arid climatic conditions, where the annual mean precipitation is 100mm and the temperature exceeds 40°C in the summer. The source of irrigation and even for life in this entire region is the water extracted from non-renewable aquifers. Nefzaoua is the right environment for palm trees to grow.

Nefzaoua's hydrogeology is composed of three main water sources: the superficial aquifer, 15-50m deep spread locally under each oasis, the Continental Terminal aquifer lying under the entire Nefzaoua (and formed by many sub-aquifers 300 to 600 m deep) and the Intercalary Continental aquifer also formed by three sub-aquifers between 1000 and 2200 m in depth and extending to the international boundary shared between Tunisia, Algeria and Libya. The Continental Terminal aquifer covers an area of 350,000 km_ in northern Sahara. The important part is in Algeria. This aquifer has a different piezometric level depending on the thickness of the aquifer that increases from the Djebel Tebaga to the southwest. Until the sixties, the piezometric level was a few meters in Kebili and some 25m in Guettaya, where, in the fifties, some springs were yielding more than 100 l/s. The Intercalary Continental aquifer covers an area of 600,000 km^2 in northern Sahara. The important part is in Tunisia. Its water has a temperature of +65°C and it is drilled in Kebili and Seftimi. It is fed only from the extremities of the Saharan basin. Its formation took place in the quaternary precipitation periods. Isotopic dating shows ages between 28,000 and 42,000 years (Kassah, 1996; Mamou and Kassah, 2002).

This complex multi-aquifer region constitutes the main water resource for domestic and agriculture use in the south of Tunisia. The interaction between the different aquifers is very complex. As mentioned above, it seems that there is some local water seepage from some underneath aquifers to the upper ones following internal fractures contaminating the upper aquifers.

2.2. Salinization of aquifers

Irrigated agriculture not only competes for water but also often contributes to the major degradation of water resources. Governmentally-induced expansion of irrigated agriculture over the last 50 years as well as uncoordinated growth of private farming activity induced a considerable overexploitation of the fossil groundwater basins. For example, over the last two decades the oases in southern Tunisia have seen significant expansion in their area: 6059ha of extension (Regional Commissariat of Agricultural Development of Kebili “CRDA”, 1996). The water exploitation from the Continental aquifers of the Nefzaoua saw three distinguished periods (Mamou, 1994). The first period was when the water was extracted in an artesian way from springs without human intervention. These springs were concentrated mainly on the eastern coast of the Chott Djerid. This period extended until the Second World War. The second period was when boreholes were installed in the interior of the Nefzaoua and when the water still had a high piezometric level. During this period, the water was abstracted and used without any planning or restrictions. This excessive use had a serious impact on the piezometric level. Some localized oases, which depended on this artesian water flow, were not able to survive. The third period began at the end of the seventies when a large number of boreholes equipped with pumps were installed in all the oases of the Nefzaoua region. The increasing number of illegal wells is a core component of this third period. Most of this abstraction is carried out from the Terminal Complex aquifer. The extensive submersion irrigation method that fills the basins in fields, requiring enormous water quantities, can be one of the causes for salinization. We call now these illegal wells as private farmers.

In the vicinity of the Nefzaoua, the change in the hydraulic regime caused local deterioration of pumped water quality due to the presence of various pollution sources of highly mineralized waters. The low quality water, mainly abstracted from the local oases aquifers located between 15 and 30m in depth, still causes much harm to the soil. This aquifer captures all irrigation water percolating downward, which is then pumped again for irrigation with a high concentration of salt. Other sources of salinization are possibly the water seeping from the Chott-Djerid or originating from the Complex Terminal aquifer, where the gypsum of this layer is dissolved and delivered through the abstracted water used for irrigation.

Consequently, salinity of pumped water has risen up to 8g/l in certain areas thus rendering this water no longer suitable for irrigation purposes. In some oases, this salinization has seriously affected production. Salty soil and water are a new phenomenon for Nefzaoua farmers since they have never experienced it before 1980. Before the end of the seventies, 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. Salinization arises in arid areas largely because two essential resources, irrigation water and the assimilative capacity of unconfined aquifers, are not priced or allocated correctly to reflect scarcity values and opportunity costs. Hence, careful future water management has to be introduced and the potential for water saving measures investigated in order not to accelerate groundwater quality deterioration that threatens the whole productive base of this region.

3. Data and Ir rigation Management Systems

The study was conducted in two irrigation systems-GIC system and a private one- which are distinguished according to their managerial form. The first one is formed of managing bodies (Groupements d'intérêt collectif or GIC) for individual oases while the second category is formed of private farmers.

GIC farmers get water and land allocated based on a communal agreement upon the distribution of the resources. Furthermore, responsibility is handed over to the individual with regard to the maintenance of the conveying system as well as the periodic clearing to the drainage channels. Irrigation management consists of structural activity (design, construction, operation, and maintenance), water use activity (water acquisition, scheduling, and distribution), and organizational activity (decision making, resource mobilization, and conflict management). The government financed the initial construction of oasis irrigation systems. Irrigation management is undertaken by water user groups (GIC) with a government subsidy for the maintenance and operation of the main canal and drilling of well. The majority of GIC farmers have been facing diminished water supply and the problem of salinity. By 2000, approximately 100 GICs were operating in the Nefzaoua Oases. Contrary to that, private farmers are not served by GIC water. They get irrigation water either from buying water quota from abandoned schemes or by drilling boreholes into the Complex Terminal aquifer tapping water from shallow wells. The CRDA does not formally approve the drilling of private boreholes nor in any way support these farms.

In the area of institutional reform, the devolution of management and financial responsibility from irrigation-system managers to local user groups has gained prominence. The popular terms for this are participatory irrigation management (PIM), which usually refers to the level, mode and intensity of user-group participation that would increase farmer responsibility in the management process (Groenfeldt and Svendsen, 2000). The interest in transfer of responsibility to user groups rests, in large part, on the desire of many governments to reduce expenditures on irrigation. Among proponents, it also argued that handing responsibility to local user groups will result in better O&M and increased productivity. PIM has become one of the cornerstones of the World Bank water-management policy (Groenfeldt and Svendsen, 2000).

All primary data for this study were collected by random sampling of farmers from different areas in the Nefzaoua oases during two field campaigns (autumn 2002 and autumn 2003). Data were collected by a team of field research assistants with the help of the Tunisian Ministry of Agriculture and a team of the ETH Zürich (Swiss Federal Institute of Technology). The criteria for the selection of the oases to be sampled were discussed with representatives of the DGRE (General Direction of Water Resources) in Tunis and the CRDA in Kebili. The inclusion of the study goals in the selection procedure ensured that oases affected by various levels of salinity were chosen. At first, in autumn 2002, five oases managed by GIC were selected from different levels of soil and salinity. The GIC selected were Tifout, Glea, Souk elbayez, Douz and Hsay. In autumn 2003, eight oases owned by private farmers, that are not served by GIC water, were selected: Blidet, Douz, Gemna, Golaa, Kalouamen, Kebili, Nouil and Zaafrane. Note that the private oases of Douz and Golaa are recent extensions on the fringes of the ancient oases.

In total, 138 GIC farmers and 144 private farmers (from which 10 farmers were removed from the data because they are new farmers and they don't have production) were randomly selected and interviewed with a questionnaire. This questionnaire was used to collect three types of data:

- Basic information about the families including, in particular, farm location, size, age, education, experience, number of days worked in agriculture, etc.
- Information about each plot of land. Data include size of plot, type of crop, and type of labour contact used, production levels, and precise amounts of labour inputs as

Tab. 1. *Description of date yield, Inputs and Farm-Specific Variables*

Variable name	Description
date yield (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)	Total labour used in date production, number of days/an/ palm-tree.
Phosphate (X_3)	Amount of phosphate used, kg/ palm-tree
Farmyard manure (X_4)	Amount of farmyard manure applied, t/palm-tree
Salinity of irrigation water (X_5)	Quality of water, g/l
Farm-specific socioeconomic variables	
Farmer's education dummy (Z_1)	Value 1 if the number of years of education of farmer is below seven, 0 otherwise
Farmer's family size (Z_2)	Number of member of household
Farmer's experience (Z_8)	Farmer's experience in date production in the study area, number of years.
Farm size (Z_4)	Total farm size, are
Farmer's number of parcels (Z_5)	Total number of parcels irrigated
Private well dummy (Z_6)	Value 1 if farmer has a private well, 0 otherwise
Farm propriety dummy (Z_7)	Value 1 if farmer is landlord, 0 otherwise
Salinity of irrigation water (Z_8)	Quality of water, g/l

Tab. 2. *Summary Statistics of date yield, Inputs and Farm-Specific Variables*

Variable	Mean		Minimum		Maximum		Standard deviation	
	GIC oases	Private oases	GIC oases	Private oases	GIC oases	Private oases	GIC oases	Private oases
Y	24.5	38.39	2.377	9	80	102	15.65	17.66
X_1	151.2	462.83	12	54.22	2332	3801	211.64	414.05
X_2	2.437	3.023	0.1	0.12	39	12.41	3.818	1.906
X_3	1.677	2.272	0	0	8.33	12	2.29	2.135
X_4	0.051	0.070	0	0	0.6	0.4	0.065	0.067
X_5	4.12	2.288	1.8	1	7	4	1.74	0.820
Z_1	-	0.738	-	0	-	1	-	0.44
Z_2	-	6.95	-	2	-	16	-	2.609
Z_3	-	15.43	-	2	-	50	-	6.313
Z_4	88.45	208.2	0.15	12.5	1000	7000	120.5	615.6
Z_5	2.15	-	1	-	22	-	2.19	-
Z_6	0.05	-	0	-	1	-	0.22	-
Z_7	0.71	-	0	-	1	-	0.455	-

well as precise amounts of other inputs.

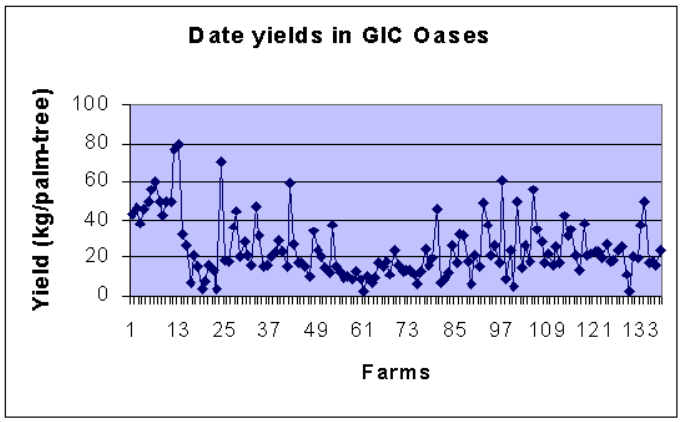
- In addition, data concerning the various aspects of irrigation management (such as water distribution, the timing and the frequency of irrigation), salinity of groundwater and soil salinity were also collected[1].

[1] For more details on questionnaire, data and the management of oases systems, see Belloumi and Matoussi, 2004 and 2005.

4. Variations in date yield and inputs used

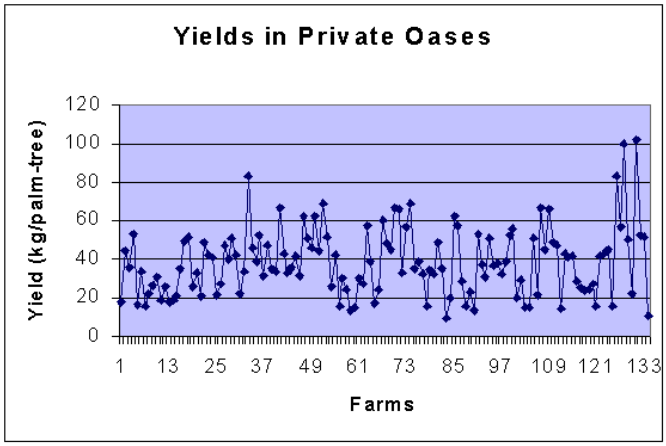
To determine date yields, crop-cutting experiments were undertaken in all the selected oases, i.e., 138 farms in the G-IC system and 134 farms in the private one. The description of all variables used in this study was presented in Table 1, and their summary statistics were presented in Table 2 for both systems. As shown in figures 1 and 2, inter-farm yield

Fig. 1. *Farm-level irrigated date yields in GIC system*



Note: Based on crop cutting experiment in the study oases, 2002

Fig. 2. *Farm-level irrigated date yields in private system*



Note: Based on crop cutting experiment in the study oases, 2003

variations in the private system were less high than in the GIC one. The yield gap in the private system was less wide than that in GIC one. The variation coefficient (VC) of date yields was lower for distributaries in private system (46 percent) than that in GIC (63 percent). Average date yields were higher in the private system (38.39 kg/palm-tree) than in the GIC one (24.5 kg/ palm-tree). In private oases, minimum and maximum yields obtained by farmers are 9 kg/palm-tree and 102 kg/palm-tree respectively, whereas in GIC oases the minimum and maximum yields are 2.37 kg/palm-tree and 80 kg/palm-tree (see Table 2). Overall in-

equity in date yields was higher in the GIC system than in the private one. The estimated Gini coefficients for private and GIC systems were 0.304 and 0.353 respectively.

The performance of the oases system is influenced by soil-water related management factors as well as socioeconomic and environmental constraints. Date production is mainly related to water supply allocation, its distribution and its quality. In general, the relationship between crop production and applied water is specified according to different considerations of what constitutes a desirable level of water use: Agronomists often aim for the level of water inputs necessary to achieve maximum yield per unit of land area; Irrigation engineers desire to maximize the efficiency of irrigation water use; and finally Economists argue that water, to be used efficiently, should be applied up to the point where the price of the last unit of water applied is just equal to the revenue obtained as a result of its application (Zhang, 2003).

In the two systems of Nefzaoua Oases, farmers have mainly water problems. Water allowance is generally not sufficient to irrigate the total landholding of a farmer. Typically GIC farmers receive less water compared to the private ones, and must depend more heavily on groundwater of variable quality. Average groundwater applied for date in the private system was 462.839 m^3/palm-tree/year compared to 151.22 m^3/palm-tree/year in the GIC one. Yield variations in these systems were high. Yield variations among farms could be even higher. This was primarily attributed to water-related constraints- namely, less quantity of water, frequency of irrigation (number of watering) and poor-quality groundwater. These constraints to a great extent affect agricultural practices among farmers in terms of input variables giving rise to large yield variations.

Fig. 3. *Effect of water quantity on date yields in private system*

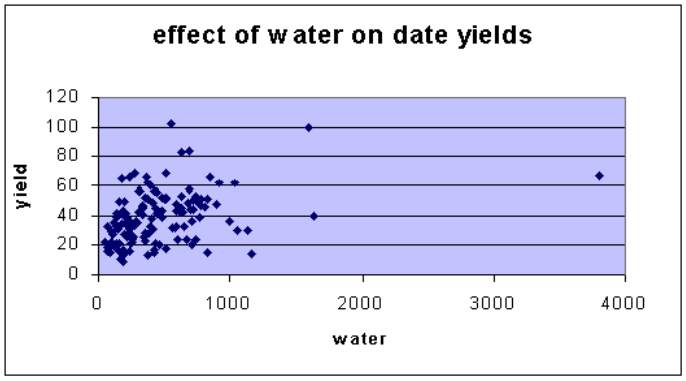
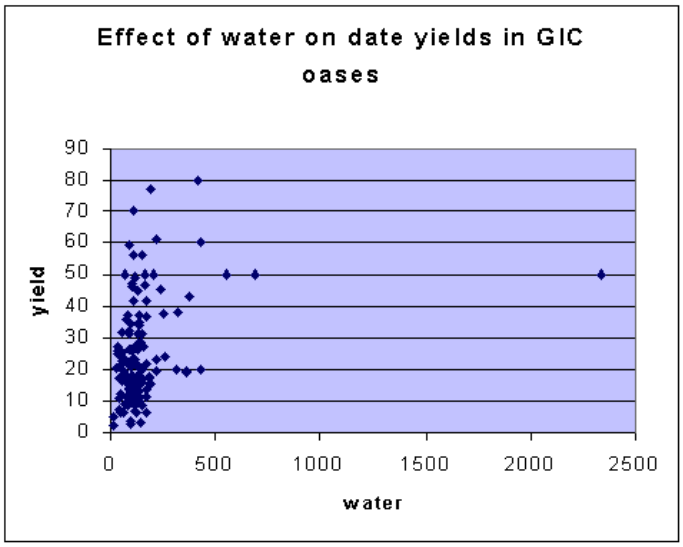


Fig. 4. *Effect of water quantity on date yields in GIC system*



In this work, we considered only the effect of the quantity and the quality of applied water on date yields. Figures 3 and 4 described these relationships in both systems. The use of saline water in crop production enlarges the available water resource but at the cost of lower yields and possible long-term effects on soil structure and soil productivity. Kijne (2003) showed that "the relationship between yield and amount and quality of the applied water is not well known under field conditions, where crops are subject to periodic and simultaneous water and salt stress and to non-uniform water application. Accordingly, knowing how much water to apply is important in terms of the sustainability of irrigated agriculture".

The salinity of water affects negatively the date yields of farmers. In fact, date yield levels were lower for GIC farmers than private farmers because GIC Oases were gravely affected by salinity of water. In GIC oases, the mean of degree of salinity in the sample was equal to 4.12 g/l whereas was equal to only 2.28 g/l in private ones. The distribution of farmers relative to degree of salinity was quite different in the two samples. In GIC sample, 31 farmers have a degree of salinity lower than or equal to 2.6 g/l and 63 farmers have a degree of salinity higher than 4 g/l. However, in private samples, these values were equal to only 97 and 0 farmers, respectively. The coefficient of correlation between date yields and degree of salinity was equal to -0.464 and -0.093, respectively in GIC sample and private sample. Aslam (1998) found "salinity and water-logging to be the major constraints on increasing wheat productivity in Pakistan. He found that losses in wheat yields in slightly saline soils could be about 36 percent compared to normal soils, and in moderately saline and highly saline soils, wheat yield could be reduced by 68 percent and 84 percent, respectively".

5. Date yield and water productivity functions analysis

5.1. Estimation of date yield function

The yield function analysis was carried out to identify and estimate the combined effects of various factors of production with a view to assessing their importance in influencing date yields. The yield function is a formal representation of a set of hypotheses that the identified production

factors influence yields and that their effects on yields are of varying magnitude. The analysis was undertaken for an entire sample for GIC system and private one separately. The yield function was specified using a range of variables, including those discussed earlier, and estimated with a log-log (Cobb-Douglas) functional form[1].

The productivity of date depends on a range of factors, including: (1) water and land related factors (such as quality and quantity of water, timing of water application, quality of land, etc.); (2) agronomic factors including quality, quantity, and timing of input application (seed, fertilizers, labour, etc.,); (3) socioeconomic factors (farmers' education level and experience in farming, farm size, tenancy terms, land fragmentation); and (4) farm management factors (adoption of modern production technology, farm planning and management practices, etc.).

There is an enormous amount of literature analyzing determinants of crop yields in developing countries. Most past studies analyzing determinants of crop productivity have focused mostly on soil and agronomic factors, with only few attempting to analyze water-related factors at the system and farm levels in a more rigorous manner. Some of these factors may be interrelated and the effect of some of these may be much smaller than that of others; here we focus on the major factors influencing date productivity.

The following dates yield function for GIC system and private one was finally estimated with a set of independent variables as given below.

$$\ln Y_i = \beta_0 + \beta_1 \ln X_{1i} + \beta_2 \ln X_{2i} + \beta_3 \ln X_{3i} + \beta_4 \ln X_{4i} + \beta_5 X_{5i} + \varepsilon_i \quad (1)$$

Where: Y denotes the date yield; X_1: irrigated water; X_2: Labour; X_3: phosphate; X_4: Farmyard manure; and X_5: salinity of water. The β_k are parameters to be estimated; ε_i are term errors; ln is the logarithm function[2].

The results of the estimated equations are presented in Table 3. In a wide range of factors, we took only those which are significant in influencing date yields. As indicated, all coefficients are elasticity's except the coefficient of salinity. Three variables included in the model were statistically significant for the two systems. These variables were irrigation water, labour and phosphate. Their coefficients were positive as expected and statistically significant. For example, the estimated coefficient of irrigation water was positive and statistically significant with values of 0.338 and 0.135 respectively, in GIC and private system. As the coefficient value represents date yield elasticity of irrigation, the implications are that a 10% increase in irrigation water will increase yield by 3.38% and 1.35% respectively, in GIC and private system. This result implies that the effect of irrigated water was more important in GIC oases than in the private ones. In view of surplus labour in agriculture the positive sign and significant estimate of output elasticity for labour was expected in both systems. The fertiliser phosphate was statistically significant at 0.01 levels for the two systems. However, the elasticity of the fertiliser farmyard manure was insignificant for the two systems.

Tab. 3. *Estimated coefficients of date yield function and their significance*

Variable	GIC Oases		Private Oases	
	Coefficient	t-value	Coefficient	t-value
Constant	1.548[a]	3.435	2.433[a]	7.574
$\ln X_1$	0.338[a]	4.211	0.135[b]	2.437
$\ln X_2$	0.158[b]	1.954	0.299[a]	4.467
$\ln X_3$	0.235[b]	2.625	0.166[b]	2.589
$\ln X_4$	0.182	0.172	-0.469	-0.735
X_5	-0.172[a]	-5.958	-0.045	-1.084
R^2	0.426	–	0.377	-
F	18.327	–	15.532	-
N	138	–	134	-

(a) significant at 1%;(b) significant at 5%; (c) significant at 10%.

In addition to quantity, the quality of water is an important factor influencing yields. The variable salinity of water had a negative impact on date yields in the two systems but its coefficient was significant at 0 percent only for GIC system. This is because the groundwater salinity levels are very high in GIC oases.

Hence, the model was globally significant at 0 percent for both equations; the coefficients of determination of the estimated equations were relatively low because the data being used in estimations were cross-sectional.

5.2. Irrigation water productivity of date

5.2.1. Average and Marginal Productivities of Water

Increasing the productivity of water in agriculture will play a vital role in easing competition for scarce resources, prevention of environmental degradation and provision of food security. The argument for this statement is simple: by growing more food with less water, more water will be available for other natural and human uses (Molden et al., 2003).

The first task in understanding how to increase water productivity is to understand what it means. As presented by Molden et al. (2003), the definition is scale-dependent. For a farmer, it means getting more crop per drop of irrigation water. But, for a society as a whole, concerned with a basin or country's water resource, this means getting more value per unit of water resource used. Increasing water productivity is then the business of several actors working in harmony at plant, field and irrigation system. The classical concept of irrigation efficiency as used by engineers omits economic values. To determine optimum-level irrigation efficiency, the economist would like to know the value of ir-

[2] The popular econometric and statistical criteria, such as consistency and plausibility of estimated coefficients, algebraic signs and numerical magnitudes and their statistical significance, were used to select this functional form that had the best fit for the given data set.

rigation water and the cost of increased control or management that would permit a reduction in diversion. As water becomes scarce, increasing crop water productivity or reducing diversions would make sense if the water 'saved' could be put to higher-valued uses. Moreover, water productivity or yield per unit of water is a partial productivity of just one factor, whereas the most encompassing measure of productivity used by economists is total factor productivity. But the concept of partial productivity is more widely used by economists and non-economists alike.

The following definitions may help understanding the differences between various productivity parameters. Pure physical productivity is defined as the quantity of the product divided by the quantity of the input - for example, yield per cubic metre of water diverted or depleted. Combined physical and economic productivity is defined in terms of either the gross or the net present value of the crop divided by the amount of water diverted or depleted. Economic productivity is the gross or net present value of the product divided by the value of the water diverted or depleted, which can be defined in terms of its opportunity cost in the highest alternative use.

To determine factors affecting farmer's performance in irrigation management, some performance criteria are needed. For example, irrigation water productivity was used as an index of water use efficiency. Average and marginal productivities of irrigation water were estimated as follows:

$$AP_1 = Y/x_1 = MP_1/e_{x1} \qquad (2)$$

$$MP_1 = ?\,Y/?\,x_1 = AP_1\, e_{x1} \qquad (3)$$

Where AP_1 is the average productivity of irrigation water; MP_1 is the marginal productivity of irrigation water and e_{x1} is the elasticity of date yield to irrigation water.

The summary statistics of average and marginal productivities of water for the GIC farmers and private ones are summarized in Tables 4 and 5. The mean values of average water productivity were estimated to be 0.185 kg/m^3 and 0.121 kg/m^3, with ranges from 0 to 0.754 and from 0.011 to 0.445, respectively for GIC oases and private systems. These results indicated that one cubic meter of water produced on average 0.185 kg of date per year in GIC system and 0.121 kg of date per year in the private one. The median values indicated that about 50% of farmers had an irrigation water average productivity indices under 0.135 and 0.098, respectively for GIC oases and private systems. These values are similar to those obtained in 1995 for water productivity of rice and of other cereals. For example, water productivity of rice ranged from 0.15 to 0.60 kg/m^3, while that of other cereals varied from 0.2 to 2.4 kg/m^3 in 1995. The global average water productivity of rice and of other cereals was 0.39 kg/m^3 and 0.67 kg/m^3, respectively in 1995 (Cai and Rosegrant, 2003). Hussain et al. (2003) found "that consumed water productivity of wheat is similar for the selected systems in India and Pakistan (1.36 kg/m^3 in India and 1.37 kg/m^3 in Pakistan)".

The mean values of marginal productivity of irrigation water were estimated to be 0.071 and 0.016, with ranges from 0 to 0.292 and from 0.013 to 0.060, respectively for GIC oases and private systems. These results indicated that an addition of one cubic meter of water could increase on average the date production by 0.071kg per year in GIC system and by 0.016 kg of date per year in the private one. The median values of marginal productivity of irrigation water were estimated to be 0.052 and 0.013, respectively for GIC oases and private systems[3].

In summary, these statistics indicated that most farmers were recognized to have very low values of irrigation water productivities in both systems. On average, they were significantly higher for GIC system than for private one because private farmers use much water without conservation. We can conclude that the irrigation water was not productive in both systems because of the lack of water quantity and quality. The salinity of water affects negatively the date production. To increase the irrigation water productivities, we must have a best quality of water and oases farmers must odopt modern irrigation technologies, which increase yields as well as save water in most cases.

In Tunisian oases, farmers use to irrigate with traditional irrigation methods, such as flood or furrow. These methods use gravity to disperse water over a field. They have low costs of adoption, but are also relatively inefficient with water use. Modern technologies such as micro-sprinkler or drip irrigation have higher adoption costs, but deliver the water directly to the crop, applying water in a more precise fashion than traditional technologies.

Tab. 4. *Summary statistics of average and marginal productivities in GIC Oases*

Productivity indices	GIC Oases				
	Mean	Median	Maximum	Minimum	Standard deviation
Average Productivity of water (kg/m^3)	0.185	0.135	0.754	0	0.155
Marginal Productivity of water (kg/m^3)	0.071	0.052	0.292	0	0.060

Tab. 5. *Summary statistics of average and marginal productivities in Private Oases*

Productivity indices	Private Oases				
	Mean	Median	Maximum	Minimum	Standard deviation
Average Productivity of water (kg/m^3)	0.121	0.098	0.445	0.011	0.082
Marginal Productivity of water (kg/m^3)	0.016	0.013	0.060	0.001	0.011

[3] Zhang (2003) used a quadratic production function to describe the response of wheat yield to total applied water.

5.2.2. The effect of farm-specific factors on irrigation water productivity

Various factors, including crop genetic material, water-management practices, agronomic practices and the economic, social, physical, institutional and personal factors, affect water productivities. We test here only the effect of some socioeconomic and environmental factors on average productivity of water in both systems.

The following water productivity linear function for GIC and private systems was finally estimated with a set of socioeconomic and environmental factors as given below.

$$AP_i = \delta_0 + \delta_1 Z_{1i} + \delta_2 Z_{2i} + \delta_3 Z_{3i} + \delta_4 Z_{4i} + \\ + \delta_5 Z_{5i} + \delta_6 Z_{6i} + \delta_7 Z_{7i} + \delta_8 Z_{8i} + \varepsilon_i. \quad (4)$$

Where: AP denotes the average water productivity; Z_i denote farm-specific socioeconomic and environmental factors specified in Table 1. The ∂_k are parameters to be estimated; ε_i are term errors.

We consider only the factors which are significant. They were education, farmer's family size, experience, farm size, number of parcels, having a private well or not, the nature of propriety of the farm and the salinity of irrigation water. Using ordinary least squares method, the effects of these factors on the water productivity were estimated. Results were shown in Table 6.

As indicated, only the variable “farm size” was significant for both equations. Its impact on the average productivity of water was positive. This means that farmers with larger irrigated area were likely to be more productive with respect to the use of irrigation water. This result was expected because large farms can operate modern agricultural equipment and manage irrigation more effectively. For GIC system, three other variables (Z_6, Z_7 and Z_8) were significant. The farmers having private well were more productive than others. The farmer that is landlord is more productive. The coefficient associated with the degree of salinity of water is of particular interest. The effect of salinity on the average productivity of water was negative and very important. It implies that if the degree of salinity of water increases, the average productivity of water decreases. The effect of farmer's number of parcels on efficiency levels was negative but insignificant. This result was expected because the number of plots reduces the effort of the farmer. All the other variables, which were not significant, were excluded from the model.

For private system, on the basis of asymptotic t-ratios, three other variables (Z_1, Z_2 and Z_3) were significant in explaining average productivity of water levels. The coefficient for the education dummy was negative. It shows that the more a farmer is educated the more productive he will be. The farmer's family size had a positive effect on average productivity of water levels. The farmer's experience had a positive effect.

The values of R^2 were weak for both equations because the dependent variables were rates.

Tab. 6. *Least square d estim ates of irrigation water pro ductivity models*

Variable	GIC Oases		Private Oases	
	Coefficient	t-value	Coefficient	t-value
Constant	0.236 [a]	5.926	0.0514 [b]	1.974
Z_1	–	–	-0.0294 [c]	-1.851
Z_2	–	–	0.0059 [b]	2.207
Z_3	–	–	0.0029 [a]	2.680
Z_4	0.0002 [c]	1.715	2.55E-05 [b]	2.279
Z_5	-0.0094	-1.097	–	-
Z_6	0.0991 [c]	1.710	–	-
Z_7	0.0638 [b]	2.290	–	-
Z_8	-0.0253 [a]	-3.423	–	-
R^2	0.157	–	0.127	-
F	4.941 [a]	–	4.703 [a]	-
N	138	–	134	-

(a) signific ant at 1%;(b) significant at 5%; (c) signific ant at 10%.

6. Conclusions and policy implications

This study takes a holistic approach by rigorously analyzing a fairly comprehensive set of factors including agronomic and water-related factors (such as quantity and quality), and their influence on date yields in the irrigation systems in the Nefzaoua Oases of Tunisia, with analysis of factors at both farm and irrigation system levels. Key findings of the work are summarized below.

- The difference of average date yields in the GIC system (24.5 kg/ palm-tree) and the private one (38.39 kg/palm-tree) in the Tunisia Oases is high.
- There are significant differences in yields across farms in irrigation systems, with much greater yield variations in GIC system than in the private one.
- The average productivity of applied water is higher for GIC oases (0.185 kg/m^3) than for private ones (0.121 kg/m^3).
- The quality of groundwater is relatively poor in both systems and more so in GIC oases, while the average productivity per palm tree is lower where groundwater is of poorer quality.
- The main difference between both systems is the water salinity which affects negatively date yields and water productivity in GIC oases.

The results of the estimated yield functions suggest that water salinity and quantity of applied water are important factors influencing date yields. The poor groundwater quality in GIC oases, leading to accumulation of salts, is one of the key factors contributing to yield differences intra and inter systems. Besides, the results of the estimated water productivity functions suggest that socioeconomic and environmental factors, which affect water productivity, were not the same. In GIC system, four variables were significant: farm size, 'having a private well or not' dummy, the 'nature of landed propriety' dummy and water salinity. In the private one, they were farm size, farmer's experience, education dummy and the number of family members.

To find solutions to the water problems many developing countries face, we need a better understanding of how we have used water to grow food and to improve rural livelihoods. We need to know which investments in water for irrigated agriculture have reduced poverty and increased food security - and which have not. We need to better understand not only the benefits of irrigation, but also the costs in terms of environmental degradation and pollution. Water productivity[4] of irrigation is quite low in both systems. This is really a pity in oases where water is increasingly scarce, both in terms of quantity and quality. To increase the productivity of water, farmers should adopt the most modern techniques of irrigation such as drip irrigation. Oases farmers use one of the oldest method of irrigating fields which is surface irrigation (also known as flood or furrow irrigation), which means a lot of wasted water.

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[4] Water productivity measures seem very low because all their summury statistics in both systems are measured by considering only dates which can be consumed by humans. For example, a palm tree can give a yield of 120 kg but only 60 kg can be consumed, the rest must be rejected and given to animals because the quality is very poor.