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# Technical performance and water productivity analysis of the irrigated durum wheat activity

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**Abstract –** Within the context of climate change and increasing water scarcity, the development of irrigated agriculture is required as main lever in order to deal with the food challenges. Tunisia is facing an imminent risk of water shortage given that the policy of the water supply reached its limit while the currently water availability is already below the poverty line (450m$^3$/capita/year).The irrigated agriculture consumes 80% of the water availability and therefore it remains the main sector that might provide water saving for the other sectors. However, the irrigated activities should achieve optimum yields in order to increase production and to meet the population needs. The irrigated cereal crops which account for only 7% of the total cereal area contributed with 25% of the total cereal production. However, the achieved yields are far from the expected potential level. This reveals a crucial question regarding the productivity and the efficient use of the water resources. In order to deal with this issue, field surveys were carried out among a sample of 120 farmers in the governorates of Beja and Siliana by addressing the farming system during the cropping year of 2013-2014. By using two-step nonparametric approach, the optimal production of the durum wheat crop was estimated in order to assess the importance of the production deviation and to identify possible alternatives for improvement. The results showed that the water productivity is under the expected potential given that the average of the sample productivity reached only 8kgha$^{-1}$mm$^{-1}$. The estimated production frontier suggests that the durum wheat production could be increased by 28% by mastering perfectly the technology process. The results showed also that this improvement is plausible especially among farmers receiving agricultural training. Moreover, farmers might reach better production among large size plots and by practicing suitable crop rotation.

**Keywords:** Irrigated activity, technical efficiency, water use efficiency, DEA model, Tobit model.

## 1. Introduction

By 2050, the global population will reach 9 billion and the main challenge remains how to feed it given the limited resources within the context of the climate change. In fact, the increase of the food demand and the unwise uses of the resources let the production efforts unable to meet population needs. Prospective studies show that the consumption per capita will exceed 3000 kcal/day in 2050. Combined with the population growth the overall demand for agricultural products should grow at 1.1% per year. Hence, FAO expects that the agricultural product should increase by 60% in order to satisfy the food demand in 2050 (Alexandratos 2012)

Moreover, agricultural activity is facing resources constraints that may jeopardize the product efforts to feed the growing population. The major concerns are the land and water availability. In fact, projections show that the available land will decrease to reach 0.181 ha/capita by 2050 while it was over 0.4 ha/capita in 1960. The water scarcity threatens many countries in the world mainly developing ones given that the projections showed that the water supply will decrease under 6000 m$^3$/capita by 2030 while it was over 12000m$^3$/capita in 1960s. Moreover one considers that any country using more than 20% of its renewable resources for irrigation is considered as crossing the threshold of impending water scarcity (Alexandratos 2012; Postel 2000).

Tunisia is facing the same trends mainly an imminent risk of water shortage given that the policy of the water supply reached its limit while the currently water availability is already below the poverty line (450m$^3$/capita/year).The irrigated agriculture consumes 80% of the water availability and therefore it remains the main sector that might provide water saving for the other sectors. However, the irrigation sector plays the key role in the agricultural development by providing 35% of the national agricultural production and Tunisian government plans to increase this share to reach 50%. Hence, the irrigated activities should achieve optimum yields in order to increase production and to meet the population needs

In the other hand, the irrigated areas suffer from many difficulties such as aging of the pipe line equipments, soil salinization and unwise uses of the water resources. Regarding the irrigated crops, the cereal activity ensure in average 20% of the cereal product up to 40% in the arid year. Despite this role, the achieved yield remains under the potential expected level which should reach 70 qx/ha and more (Lasram et al. 2015). Hence, one should ask two main questions: (i) what are the optimal yields that might be achieved by using resources efficiently? and (ii) what are the significant factors impacting the production process? In order to deal with these issues, we rely our research on the following assumption: Given the observed mix of inputs, farmers should achieve higher yields than the currently reached level. Hence, the first step of this research will analyze the technical efficiency of the irrigated durum wheat activity while the second one will attend to identify some factors, which are impacting its variability.

## 2. Material and Methods

### 2.1. Cereal sector and importance of the irrigated activity

The cereal sector remains the main strategic activity in Tunisia. The cultivated area reaches an average of 1.4 million hectares per year which represents the third of the arable land. The cereal activity is experienced by more than 250 000 farms representing around 50% of the total number of Tunisian farms. Also, cereal activity provides 2 millions work days per year and contributes with 13% in the agricultural GDP. However, cereal sector is mainly rainfed activity. Hence, as showed in the Figure 1, the cultivated area fluctuates from year to year. This phenomenon affects seriously the production which shows huge fluctuation (Figure 2) and had decreased till 5 Million qx in 2002 which covers only 18% of the country needs.

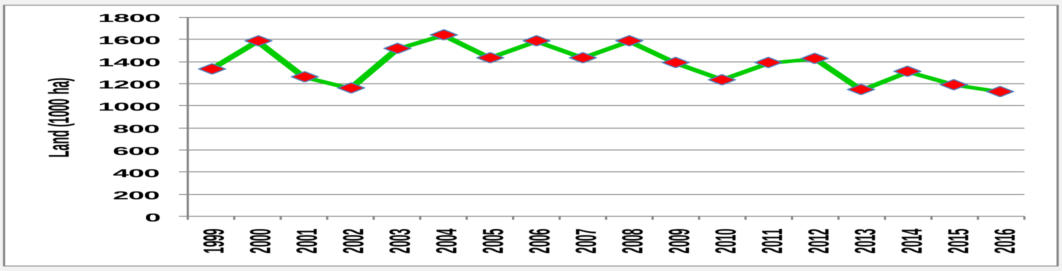


**Figure 1.** Evolution of cereal area

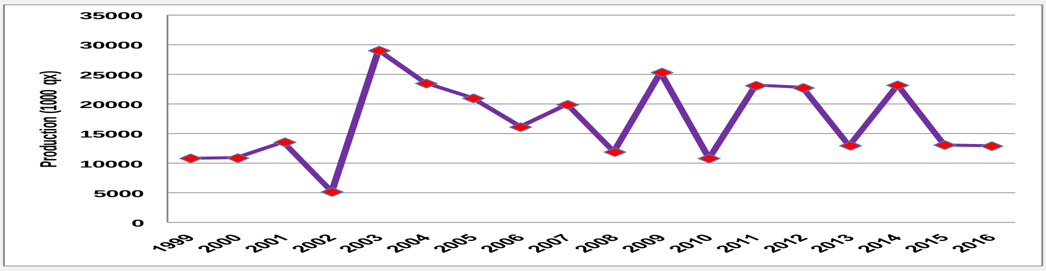


**Figure 2.** Evolution of cereal production

In order to minimize this fluctuation, the irrigated cereal activity was developed. The cultivated area reaches an average of 80 000 ha per year up to 100000 ha in 2010 (Figure 3). This irrigated activity which represents only 6% of the total cereal area provides yearly an average of 2.7 million qx which covering around 22% of the national production up to 40% such as in 2002. This production showed less fluctuation (Figure 4) than the rainfed production ensuring the minimum of cereal quantity. These achievements are allowed thanks to the state efforts towards the development of the irrigated activity through enormous encouragements provided to farmers (subvention of the irrigated equipments, preferential water price…).

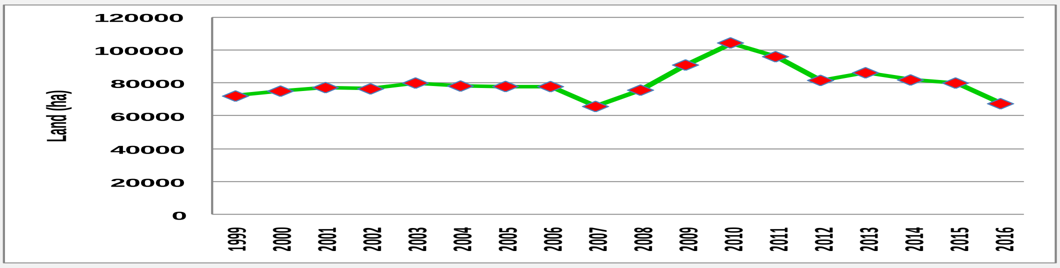


**Figure 3.** Evolution of the irrigated cereal area

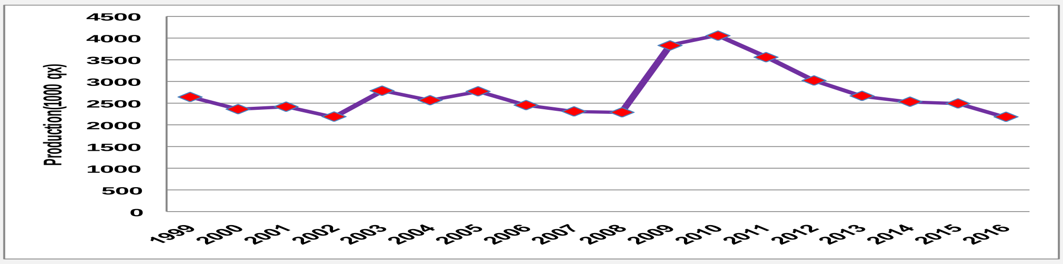


**Figure 4.** Evolution of irrigated cereal production

## 2.2. Research field and survey

Despite of the efforts to enhance the irrigated cereal activity, the reached yields remain under the expected potential. The currently average yields, 36 qx/ha should be improved in order to ensure more production and enhance the valorization of the water resources. In order to make diagnosis of the activity we have carried out survey with a sample of 120 farms belonging to two different regions, Beja and Siliana, located in the North of the country (Figure 5). The average of the rainfall reaches 600 mm/year and 400mm/year respectively in the Beja and siliana regions. In Beja, the water for irrigation is dropped from public resource (dam) while in Siliana the water is dropped from public resource (dam) as well as well from private resource (wells). This difference gives us the opportunity to analyze two different systems of the irrigation management. In fact the public resource is managed collectively by farmers with limit access while farmers owning wells as private resource benefit from free access in quantity and time.

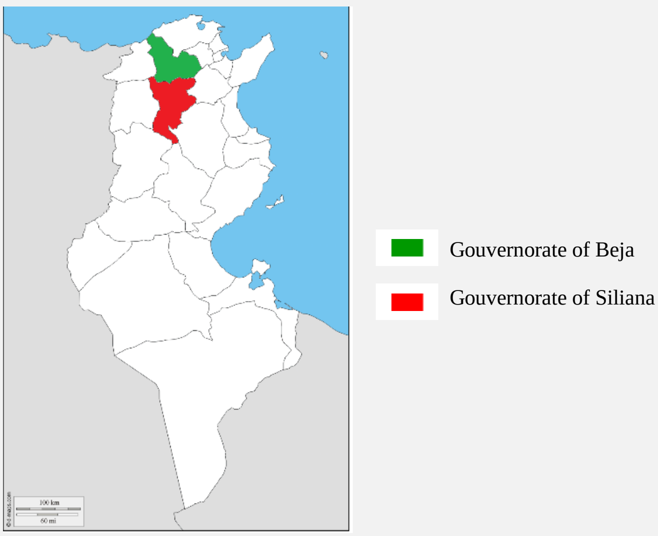


**Figure 5.** Location of the Gouvernorate Beja and Siliana

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The survey was carried out in 2015 by interviewing farmers face to face using questioner prior elaborated. Through this questioner we trend to characterize the faming system and to gather technical and economical data regarding the irrigated cereal activity experienced during the previous crop year 2014.

### 2.3. Analysis Approach

Improving the water productivity is possible by ensuring an increment yield and/or by enhancing the water use efficiency. In order to deal with issues we will assess the farms performance using the Data Envelopment Analysis (DEA) approach. In addition we trends to identify some drivers affecting this performance in order to set up suitable strategies that might help to master the technology process and to improve the productivity. For that we will estimate Tobit model.

#### 2.3.1. The DEA model

Initiated by the pioneer work of Farrell (1957), the Data Envelopment Analysis approach (DEA) allows to assess the technical efficiency of the Decision Maker Unit (DMU). A DMU is called Pareto efficient if it is not possible to raise (lower) anyone of its output (input) without lowering (increasing) at least another one of its output (input) levels and/or without increasing (lowering) at least one of its input (output) levels (Thanassoulis 2001). This approach has been widely used by scientists acting in management science and operations research (Emrouznejad and Yang 2017; Liu et al. 2013).
Let consider N DMUs of which each one produces a vector of outputs Y using a vector of inputs X. Following Charnes et al. (1978) and Banker et al. (1984), one can measure the technical efficiency (TE) of each DMU by solving the linear programs below:

$$Max_{(\lambda,k_0)}\left[k_0\right] \qquad \text{(P1)}$$

**Subject to :**

$$\sum_{i=1}^{N}\lambda_i X_i \leq X_{i_0}$$

$$\sum_{i=1}^{N}\lambda_i Y_i \geq k_0 Y_{i_0}$$

$$\lambda_i \geq 0; i = 1,\ldots, N;\ k_0 \text{ free}$$

$$Max_{(\lambda,k_0)}\left[k_0\right] \qquad \text{(P2)}$$

**Subject to :**

$$\sum_{i=1}^{N}\lambda_i X_i \leq X_{i_0}$$

$$\sum_{i=1}^{N}\lambda_i Y_i \geq k_0 Y_{i_0}$$

$$\sum_{i=1}^{N}\lambda_i = 1$$

$$\lambda_i \geq 0; i = 1,\ldots, N;\ k_0 \text{ free}$$

The technical efficiency of the $DMU_0$ is given by the following ratio: $ET_0 = \frac{1}{k_0^*}$

P1 is an output oriented model that allows to measure the technical efficiency under the assumption of Constant Return to Scale ($ET_{CRS}$) (Charnes et al. 1978) While P2 allows to compute the technical efficiency under the assumption of Variable Return to Scale ($ET_{VRS}$) (Banker et al. 1984). Hence, one can deduce the scale efficiency measure (ES) by computing the following ratio: $ES = \frac{ET_{CRS}}{ET_{VRS}}$

Furthermore, the DEA model allows to compute the Water Use Efficiency ($WUE = \phi$) by using the DEA sub-vector approach. By considering $X^v$ as the vector of the water consumption, one solves the following linear program (Färe et al. 1994; Lilienfeld and Asmild 2007):

$$Min_{(\lambda,k_0)}\left[\phi_0^v\right] \qquad \text{(P3)}$$

**Subject to :**

$$\sum_{i=1}^{N}\lambda_i X_i \le \phi_0^v X_{i_0}^v$$

$$\sum_{i=1}^{N}\lambda_i X_i \le X_{i_0}$$

$$\sum_{i=1}^{N}\lambda_i Y_i \ge Y_{i_0}$$

$$\sum_{i=1}^{N}\lambda_i = 1$$

$$\lambda_i \ge 0; i = 1,..., N;\ \phi_0 \text{ free}$$

### 2.3.2. The Tobit Model

Given that the values of the technical efficiency are bounded between 0 and 1, Tobit model remains the appropriate approach in order to identify exogenous variables that may affect the performance of the DMU and cause the variability of the efficiency scores (Tobin 1958; Dimara et al. 2005; Wossink and Demaux 2006; Wilson et al. 2001; Latruffe et al. 2002; Wadud 2003). The theoretical structure of the model is as follows:

$$ET_i = \beta_0 + \sum_{j=1}^{k}\beta_j v_{ij} + u_i$$

Where $ET_i$ is the technical efficiency score of the DMU $i$ and $v_j$ represents the explicative variables to be considered for the model estimation and $\beta$ is a vector of the coefficient to be estimated.

## 3. Results and discussion

### 3.1. Descriptive analysis

The survey was carried out among a sample of 120 farms of which 68 farms belong to Siliana region and 52 farms belong to the Beja region. The total agricultural surveyed area reached 3628 ha. Hence the average area per farms reached 30.2 ha divided into three plots. The potential irrigable area reached 2182 ha distributed between 1516 ha in the Beja region, irrigated from the dam and 666 ha in the siliana region of which 273 ha are irrigated from the dam and 393 ha are irrigated from wells as private resources. Farmers practice complimentary irrigation using mainly sprinkler system.
However the total land use during the cropping year 2013/2014 reached 2120 ha which represented only 58% of the total agricultural area. The analysis of the land use showed that the cropping system involves fruit trees (8%), cereal crops (52%), horticulture (35%) and fodder crops (5%). The total area of the cereal crops reached 1104 ha of which 705 ha are cultivated into durum wheat by 106 farmers. Therefore given the importance of the durum wheat, we will focus our analysis on this crop.

### 3.1.1. Water consumption and productivity

In order to irrigate the durum wheat, the results showed that farmers had used the available water at the level of 930 $m^3$/ha. However we should highlight the disparity between regions. In fact in Beja, the water consumption reached an average of 789 $m^3$/ha while in Siliana it was evaluated at 1034 $m^3$/ha. This difference may be explained mainly by the rainfall enrolled during the cropping year as highlighted above. In fact by considering only the farms from the public irrigated area this difference was well confirmed by reaching a consumption of 1191 $m^3$/ha in Siliana. The disparity exists also by taking into account the type of the water resource. In fact, farmers from the private irrigated area of Siliana consumed only 849 $m^3$/ha.

The practice of the complementary irrigation allowed the surveyed farmers to achieve an average yield of 39 qx/ha. The result showed a bit difference between Siliana et Beja (39.5 qx/ha against 38.6 qx/ha). In the other hand, regarding the type of the water resource the difference effectively exists. In fact, farms from private irrigated area of Siliana achieved 37.5 qx/ha while those from the public irrigated area achieved 41.2 qx/ha. These results may confirm the straightforward relationship between the water consumption and the achieved yields. So the water productivity remains a principal question that should be addressed. In fact given our results and by taking into account the rainfall, the productivity reached only 8kg/ha/mm which is far from the expected potential productivity that might reached 16 kg/ha/mm (Lasram et al. 2015; Sander and Win 2014). This low water productivity was also confirmed by El Amri et al. (2014) whom found the same and the lowest level of the wheat productivity between eight crops studied.

### 3.1.2. Economic analysis

The results (Table 1) showed that the total costs account for 1221.04 TND/ha. The main expenditure items are harvest and fertilization which represented 24% and 18% respectively. The irrigation costs reached 87.58 TND/ ha which represented only 7% of the total costs.

**Table 1.** Distribution of the item costs of the durum Wheat

| | DT/ha | % | Min | Max | S.D |
|---|---|---|---|---|---|
| **Seeds** | 162.28 | 13 | 69.6 | 264 | 35.43 |
| **Mecanization** | 147.94 | 12 | 45 | 367 | 60.51 |
| **Fertilization** | 218.97 | 18 | 49.5 | 378 | 76.48 |
| **Irrigation** | 87.58 | 7 | 17.82 | 393.12 | 71.02 |
| **Patologic treatment** | 144.34 | 12 | 0 | 750 | 134.53 |
| **Hired labor** | 84.40 | 7 | 6.42 | 600 | 73.94 |
| **Harvest** | 290.60 | 24 | 112 | 500 | 56.68 |
| **Transport** | 84.93 | 7 | 0 | 496 | 99.92 |
| **Total** | **1221.04** | **100** | **752.95** | **1958.70** | **276.46** |

Given the achieved yields, the total production reached an average of 2813 TND/ha (Table 2). This production allowed to gain a margin of 1592 TND/ha. The results did not show huge difference between the two regions as well as between the type of water resources. However we should highlight, that even the total costs in Siliana and the public area exceed respectively those in Beja and the private area, the achieved production value allowed better gross margin in the both cases.

**Table2.** Economical results of the durum wheat crop (TND/hectare)

| | Production | Expenditures | Gross Margin |
|---|---|---|---|
| **Beja** | 2767 | 1193 | 1574 |
| **Siliana** | 2846 | 1241 | 1605 |
| **Private resource** | 2741 | 1201 | 1540 |
| **Public resource** | 2838 | 1228 | 1610 |
| **Total** | **2813** | **1221** | **1592** |

## 3.2. Efficiency analysis

In order to assess the performance of the durum wheat activity we assume that the technology process may be represented by the function blow:

$$\text{Prod} = \boldsymbol{f}(\text{Sup, Sem, Mecan, Fert, wat})$$

**Where**

**Prod:** durum wheat production in qx
**Sup:** Cultivated area in hectare
**Sem:** The quantity of the seeds in qx
**Mecan:** The number of tillage hour
**Fert:** The quantity of used fertilizer in qx
**Wat:** The quantity of the irrigation water in $m^3$

The descriptive statics of these variables were showed in the Table 3.

**Table 3**. Descriptive Statistics of the DEA variables

| Variable | Average | Min | Max | S. D |
|---|---|---|---|---|
| **Prod (qx)** | 263.91 | 17 | 5600 | 600.94 |
| **Sup (ha)** | 6.65 | 0.5 | 140 | 14.60 |
| **Sem (qx)** | 12.31 | 1 | 266 | 27.69 |
| **Mecan (h)** | 43.16 | 2.5 | 1120 | 117.88 |
| **Fert (qx)** | 33.09 | 1 | 630 | 73.26 |
| **Wat ($m^3$)** | 5057.44 | 288 | 70000 | 8456.11 |

By considering the technology process and solving the linear program (P1) and (P2), we have computed the technical efficiency. The results (Table 4) showed that the average of the technical efficiency reaches 0.65 and 0.72 under the CRS and VRS assumption respectively. This means that, given the current level of the inputs use, the production of the durum wheat should be increased by 28%. As showed in the Table 4, only 15 farmers (14%) performed perfectly the technology process and they are able to use optimally the inputs mix. We should highlight also that only 10 farms were operated at their optimal size by reaching an efficiency scale of 100%. Regarding the type of the water resource, the results showed that farms using private resource are more technical efficient than those using the public resource.

**Table 4.** Results of the technical efficiency measurements

| | Average | Min | Max | SD | ET=1 | Public Resource | Private Resource |
|---|---|---|---|---|---|---|---|
| **$ET_{CRS}$** | 0.65 | 0.32 | 1 | 0.16 | 7 | 0.64 | 0.69 |
| **$ET_{VRS}$** | 0.72 | 0.34 | 1 | 0.17 | 15 | 0.71 | 0.76 |
| **ES** | 0.90 | 0.62 | 1 | 0.08 | 10 | 0.90 | 0.91 |
| **WUE** | 0.42 | 0.06 | 1 | 0.22 | 5 | 0.42 | 0.41 |

Improving water productivity, it is assumed also that farmers should used irrigation water more efficiently in order to save non productive quantity. Hence we have computed the water use efficiency by solving the linear program (P3). The results showed that the average of the water use efficiency reached only 42% which indicates that more than 50% of the used quantity is an overconsumption.
By clustering farms in three groups regarding their technical performance level (Table 5) the results showed that 63 farms (59.8%) achieved technical efficiency level under 75%. This means that more attention should be payed to those farms in order to improve effectively their technical performance and to gain more into the productivity. Furthermore the results showed that 69% of farms are fewer than 50% of water use efficiency which confirm that it is really possible to improve water productivity through saving the overconsumption.

**Table 5.** Distribution of the farms number regarding the level scores

| **Scores** | <0.5 | | 0.5=<scores<0.75 | | >=0.75 | |
|---|---|---|---|---|---|---|
| | **Number** | **%** | **Number** | **%** | **Number** | **%** |
| **CRS** | 20 | 18.8 | 59 | 55.7 | 27 | 25.5 |
| **VRS** | 7 | 6.6 | 56 | 52.8 | 43 | 40.6 |
| **SE** | 0 | 0 | 6 | 5.5 | 100 | 94.5 |
| **WUE** | 73 | 69 | 23 | 22 | 10 | 9 |

### 3.3. Determinants of the Technical efficiency

In order to develop suitable strategies for improving technical efficiency, we have to identify some exogenous variables that may affect the ability of farmers to master the technology process. These variables are attended to characterize the farms structure, the farming system and agronomical practices, the social components of households, the land ownerships, the market access etc. Hence in order to estimate the Tobit mode we have selected six variables as follows

**Sup** : Cultivated area in hectare
**Age** : Farmers Age
**Fag** : Agricultural training (1=yes, 0=No )
**Mfv** : Landownership (1=yes, 0=No)
**Ass** : Crops rotation practice, (1=yes, 0=No)
**Elv** : Livestock activity (1=yes, 0=No)

The descriptive statistics of these variables are presented in the Table 6.

**Table 6.** Descriptive statistics of the explicative variables

| **Variable** | Average | Min | Max | S. D |
|---|---|---|---|---|
| **Sup** | 6.65 | 1 | 140 | 14.605 |
| **Age** | 48.25 | 22 | 86 | 12.213 |
| **Fag** | 0.24 | 0 | 1 | 0.427 |
| **Mfv** | 0.81 | 0 | 1 | 0.393 |
| **Ass** | 0.57 | 0 | 1 | 0.498 |
| **Elv** | 0.61 | 0 | 1 | 0.489 |

Given this selection of variables we have estimated the following Tobit model

$$ET_{vrs} = \beta_0 + (\beta_1 * \sup) + (\beta_2 * Age) + (\beta_3 * fag) + (\beta_4 * Mfv) + (\beta_5 * Ass) + (\beta_6 * Elv) + \mu$$

The results of the estimation (Table 7) showed that four variables may explain the technical efficiency distribution and had significant impacts on the technical performance.

**Table 7.** Results of the Tobit Model

| | **LR chi(2)=36,60** | | **Prob>chi(2)=0,0000** | |
|---|---|---|---|---|
| **Variable** | Coefficient | S.E. | t | Prob>t |
| **Sup** | 0,0096 | 0,0032 | 2,93 | 0,004*** |
| **Age** | -0,0013 | 0,0014 | -0,92 | 0,361 |
| **Fag** | 0,1474 | 0,0411 | 3,58 | 0,001*** |
| **Mfv** | -0,0727 | 0,0436 | -1,67 | 0,099* |
| **Ass** | 0,0618 | 0,0342 | 1,81 | 0,074* |
| **Elv** | 0,0365 | 0,0346 | 1,05 | 0,295 |
| **Constant** | 0,7152 | 0,0865 | 8,26 | 0,000 |

***Significant at 1% *Significatif at 10%

The results showed that farmers whom cultivated large area were more technical efficient. It was proved also that farmers whom declared that they had participated to agricultural trainings achieved higher efficiency scores. The practice of the crop rotation seems to favor also a better level of technical efficiency. On the other hand the results showed that the landowners are less technical efficient than leaseholders' farmers.

By proving the weakness of the technical efficiency, the results revealed a production gap that might be catched up in order to improve the water productivity. Given the currently mix of inputs, farmers could increase their production by 28%. This means that the average of yield could be increased up to 50 qx/ha which may increase the water productivity up to10 $kgha^{-1}mm^{-1}$. Regarding the irrigation practice the results showed inefficient uses of the resource estimated at 60%. Recent studies showed that using perfectly the complementary irrigation should improve water use efficiency and therefore the increase the water productivity. Hammami et al. (2016) pointed out that complementary irrigation experienced in the public irrigated area of Mateur and Medjez el Bab (Beja) allowed a shift of yield evaluated at 33.5% and 7% respectively compared to rainfed crop production. Mailhol et al. (2004) highlighted that following a perfect irrigation scheduling and irrigation doses, the achieved yield might reach 60 qx/ha.

However, the possibility to enhance water use efficiency and to increase the water productivity supposes the disposal of some farms' physical features and household characteristics. In our case, we have demonstrated that holding and cultivating large area have a positive effect on the technical efficiency and therefore improve the water productivity. This result was confirmed also by numerous previous studies (Chebil et al. 2013; Albouchi et al. 2007; Chemak et al. 2014)

Benbella et al. (2003) argued that the adoption of economic irrigation system and novel techniques allowed rational use of the water irrigation and improved the productivity. In order to master these techniques farmers need training and some technical assistance. According to this, our results showed that farmers receiving training were more technical efficient as confirmed also by Frija et al. (2009)

On the other hand, in order to improving water productivity farmers should perform some agronomical rules and practices. Our results showed that farmers practiced crop rotation are more technical efficient. As analyzed by Hatfield et al. (2001) and Tennakoon and Hullugalle (2006) the crop rotation may improve the water use efficiency by 25% up to 40%.

## 4. Conclusion

Improving water productivity remains one of the main alternatives to deal with the water scarcity issues and to ensure agriculture production to meet population needs. Tunisia is facing serious water shortage constraints and farmers should use efficiently the water irrigation. Given the currently state of the irrigated activities and following our results, it is really possible to improve the water productivity. Our study case showed that given the currently mix of the inputs use, the production of the durum wheat should be increased by 28% which allows to improve the water productivity up to10 $kgha^{-1}mm^{-1}$

Moreover the results showed an overconsumption of the water irrigation. By achieving only 42% of the water use efficiency index, farmers are requested to invest more in piloting irrigation. Also, decision makers should pay more attention to this result in order to improve farmers' awareness about their key role in managing the water resources.

On the other hand, significant determinants were identified showing that some suitable strategies should be developed in order to improve the water productivity. For that the decision makers should set up training programs to improve farmers' skills regarding the irrigation and agronomical practices. Reviewing the law in order to enhance farmers to cultivate rented land may also encourage them to work adequately and to improve the water productivity. Moreover, sensitizing farmers to reserve large plots for the durum wheat crop will have twofold profit translated in extending the cultivated area and in enhancement of the productive performance.

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