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Water accounting for food security: the case of rainfed and irrigated olive growing in arid regions in Tunisia

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Abstract

Food and water security become challenging goals in many regions due to biophysical, socio-economic and political conditions, often amplified by climate change and other crises. In this perspective, accounting water is a crucial tool to understand the overall tendency of water consumption and to assist the decision makers in their decisional process about water and crops allocations. In this optic, the present paper aims to undertake a comparative analysis of the water use and conception in the irrigated and rainfed olive growing systems; based on an integrated method combining three key concepts of water computation: virtual water, water footprint and water productivity. The study focuses on a sample of 45 farms of irrigated and rainfed olive growing system located in Medenine and Sfax regions in Tunisia which are characterized by a semi-arid and arid climate conditions. Results show the importance of the theoretical framework adopted in clarifying the state of water consumption in a strategic sector such as the Tunisian olive growing. In addition, the different calculated indicators highlight the importance of the application of a whole technical package and a controlled and efficient use of water to improve the economic profitability of olive cultivation. Finally, the study highlights also the necessity to revise the irrigated olive growing extensions' policies under arid conditions and to orient and sensitize farms to apply complementary irrigation in critical phases of the tree.

Keywords: Accounting Water, Olive Growing, Virtual Water, Water productivity, Water Footprint.

Résumé
La sécurité alimentaire et hydrique devient un objectif difficile dans de nombreuses régions en raison des conditions biophysiques, socio-économiques et politiques, souvent amplifiées par le changement climatique et d'autres crises. Dans cette perspective, la comptabilité de l'eau est un outil crucial pour comprendre la tendance globale de la consommation d'eau et pour aider les décideurs dans leur processus décisionnel sur les allocations d'eau et de cultures. Dans cette optique, le présent article vise à entreprendre une analyse comparative de l'utilisation et de la conception de l'eau dans les systèmes oléicoles irrigués et pluviaux basée sur une méthode intégrée combinant trois concepts clés du calcul de l'eau : l'eau virtuelle, l'empreinte eau et la productivité de l'eau. L'étude porte sur un échantillon de 45 exploitations agricoles en système oléicole irrigué et pluvial situées dans les régions de Médenine et de Sfax en Tunisie qui se caractérisent par des conditions climatiques semi-arides et arides. Les résultats montrent l'importance du cadre théorique adopté dans la clarification de l'état de la consommation d'eau dans un secteur stratégique comme l'oléiculture tunisienne. De plus, les différents indicateurs calculés mettent en évidence l'importance de l'application de tout un paquet technique et d'une utilisation maîtrisée et efficace de l'eau pour améliorer la rentabilité économique de l'oléiculture. Enfin, l'étude souligne également la nécessité de réviser les politiques d'extensions oléicoles irriguées en conditions arides et d'orienter et de sensibiliser les exploitations à appliquer l'irrigation complémentaire dans les phases critiques de l'arbre.

1. Introduction

Water accounting is a central concept in thinking about water management and the sustainable development of production systems and therefore in food security in a global sense. In this context, three basic concepts will be discussed: “virtual water”, Water Footprint” and “Water productivity”. These concepts are complementary rather than competing. These indicators seem to be the most powerful indicators in water accounting to achieving food security goals. Indeed, as global demand for food increases, pressure on water resources rises. Thus, food and water security become challenging goals in many regions due to biophysical, socio-economic and political conditions, often amplified by climate change and other crises. In this perspective, water computation is therefore a crucial tool to understand the overall tendency of water consumption and can assist the decision makers in their decisional process about water and crops allocations.

Virtual water was introduced by Allan (1993) as water used in the production process of an agricultural or industrial product. It is "virtual" since it is often not physically present in the final product, which is why it has not always been counted in trade. Allan (1993) uses this indicator to describe the potential of a water-scarce country to achieve food security by purchasing part of its food needs from international markets, rather than using limited water resources to produce all of its food needs. "Virtual water" combines agronomic and economic concepts, with a focus on water as a key factor in production. The agronomic component involves the amount of water used to produce crops, while the economic component involves the opportunity cost of water. This cost is its value in other uses that may include the production of alternative crops or use in municipal, industrial or recreational activities. The "virtual water" perspective is compatible with the concept of integrated water management, in which many aspects of water supply and demand are considered to determine the optimal use of limited water resources. In particular, the profitability of water, which is a key element of the virtual water perspective, must be considered when seeking an efficient allocation of limited water resources. In addition to its liberal character as a key element in agri-food transactions and in restoring the trade water balances of countries, virtual water has an intrinsic strategic acceptance, affecting agricultural policies and water resource management policies, particularly in arid and semi-arid countries. This, allows a new conception of crop allocations based on opportunity costs and on the evaluation of certain strategic choices, as is the case of extensions of irrigated perimeters (Souissi *et al*., 2022).

Virtual water makes it possible to calculate the footprint on water, i.e., the pressure exerted by an individual or by a country on water. The water footprint was developed and defined by Hoekstra (2003) following his interest in the concept of virtual water. Closely related to this concept, the water footprint is defined as a spatio-temporal indicator, showing the volumes of water consumption for a moment or for a period of time per spatial unit (region, country, etc.) or per persons. Like virtual water, the water footprint is made up of blue, green and grey water footprints. A distinction is also made between the internal and external water footprints when estimating the water footprint of a country or region (Chapagain and Hoekstra, 2004). The internal water footprint is the volume of water used from local resources to produce the goods and services consumed by the country's inhabitants. The external water footprint is the volume of water used in other countries to produce goods and services that are imported and consumed by the inhabitants of the importing country.

While virtual water expresses the amount of water needed to produce a unit of product, and water footprint measure water used in a spatial unit (or by individual); water productivity aims the water use efficiency measurement, i.e., the amount of water used to produce a quantity of or in terms of economic benefit. Water productivity is defined as the ratio between production and the amount of water consumed in the production process. In its overall acceptance, the notion of water productivity in the agricultural sector focuses on the idea of "more crop per drop" (FAO, 2002; Giordano *et al*., 2006). In fact, these concepts and indicators have only reinforced the studies on water accounting representing value-added information to better understand and address the issue of water scarcity and its food, livelihood and environmental implications.

It should be noted that accounting water indicators have already been successfully used in several research (Dominguez, 2010; Zhao and Samson, 2012; Souissi *et al*., 2022). This, in the purpose to achieve food security goals taking into account its international implications on agri-food products transactions (import and export), virtual water is used in several studies as an indicator to analyze water management and allocation issues, especially in countries facing water scarcity (Hamdane, 2013; Fernandez *et al*., 2020). In the same context, studies of Hoekstra and Hung (2005), ZhanMing Chen (2013); Zhang and Anadon (2014) demonstrate the importance of virtual water in decision making about exporting food products and the accounting of water in trade transactions. Other researchers have studied the assessment of virtual in some productive systems such as cereal sector (Novo *et al*., 2009) and olive growing sector (Ben abdallah *et al*., 2014). Several researches were focusing in countless methodological issues and in various case studies on Water footprint (Lovarelli *et al*., 2016; D'Ambrosio *et al*., 2018; Yerli and Sahin, 2021; Ansorge and Stejskalová, 2022; Xiao *et al*., 2022) and water productivity (van Halsema *et al*., 2012; Scheierling *et al*., 2016; Zhang *et al*., 2017; Shirmohammadi-Aliakbarkhani and Afshin, 2021; Sraïri *et al*., 2021; Letseku and Grové, 2022).

In Tunisia, water is considered as a limited resource and unevenly distributed in space and time especially in semi-arid and arid areas. Indeed, the average annual rainfall varies from less than 100 mm in the extreme south and more than 1500 mm in the extreme north of the country. In these specific conditions, the olive tree was always considered as hardy species that has been able for a long time to withstand high levels of water stress in arid and semi-arid climates, characterizing the areas of Tunisia where the olive tree has experienced the most significant extensions (central and southern Tunisia). However, the prolonged water deficit or the drought can impact the plant to various degrees having negative repercussions on the productivity of the olive tree and on the regularity of productions. Various cultural interventions can be implemented to mitigate the impact of these difficult climatic conditions. These interventions are generally related to the adequacy between the development of the olive tree and the capacity of the environment to feed it, in particular to the provision of irrigation water and other interventions of safeguard (Gargouri *et al*., 2012; Ghrab *et al*., 2013; Trabelsi *et al*., 2019). It explains the diversification in recent years of olive production systems. In addition to the conventional production system in rainfed, Tunisia has other production systems that are conducted in irrigated namely: the intensive system, the dynamic system, the hyper-intensive system and the organic or biodynamic mode (Ben abdallah *et al*., 2021; Ben abdallah *et al*., 2022; Elfkih *et al*., 2022).

The extension of the intensive system in the case of the olive growing appears to be a technical imperative to regulate and increase agricultural production in regions with a rainfall deficit. Indeed, in Tunisia, rainfall is generally insufficient and very irregular so that irrigation becomes necessary for agriculture. As in most countries with arid and semi-arid climates, the agricultural sector, through irrigation, remains the most water-consuming activity, representing 70% to 80% of the overall volume consumed by all the sectors (Ben Boubaker *et al*., 2003). In Tunisia, the irrigated perimeters representing only 7% of the useful agricultural area, contribute nevertheless with 35% of the total value of the agricultural production of the country. The irrigated olive tree covers an area of more than 95,680 ha (5% of the total olive area of the country) (ONAGRI, 2021). The contribution of the surface area of the olive tree managed in irrigation to the total production is very variable given the alternation of the productions, but it represents a hard core of the production especially in the years of low production.

Following on from the above, the introduction of water computation brings with it a different vision of water accounting which requires the use of different analytical tools. Thus, in the production process, water accounting is a central component to reveal the efficiency of the use of this resource. In this context, the present paper has two purposes: firstly, it aims to account water computation indicators (virtual water and water footprint) of olive in two different growing systems. Secondly, to assess water economic productivity comparing the two studied olive growing systems (irrigated and rainfed system). The study is applied to the Sfax and Medenine regions which are two arid Tunisian regions. This comparison will be undertaken in two functional units (per Kg and per Ha) to reveal some strategic insights related to production systems' elections and to better understand the role of farmers in more efficient, sustainable and equitable water management.

2. Materials and method

To deal with the study' purposes, a methodology based on an agro-economic approach was adopted. Thus, the methodology is an integrated approach based on the main three water accounting concepts: virtual water, water footprint and water productivity. The integration of these three concepts is required by need taking into account their perfect harmony in a scientific acceptance. Three key issues will be examined: i) the virtual water used or consumed by the olive plantation and ii) the footprint calculated per spatial unit, and iii) the economic impact based on the study of water productivity indicators. The associated indicators will be calculated in the case of irrigated and rainfed olive growing systems in the two studied regions (Sfax and Medenine). To obtain more concise information, the evaluation will target farms of different surfaces' strata. The study is based on the existing primary regional data and on surveys directed with farmers of the studied region.

2.1. Study area and Sample

This study focuses on the regions of Sfax and Medenine, regions which belongs to arid bioclimatic stage where the average annual rainfall is about 182.8 mm. Olive growing represents a principal component of the agriculture of the study area where olive tree is generally extended over a sandy-silty to sandy-limono-clay soil. In Sfax and Medenine, olive growing surfaces represents respectively 83% and 95% of the total arboriculture and the average planting density of traditional rainfed olive is about (17–34 trees/Ha) with very low yields, which increasingly affects the economic viability and sustainability of the olive sector (Agridata, 2019). In addition, the irrigated olive growing surfaces are very limited in these zones in spite of the importance of irrigation to improve production facing difficult climatic conditions.

The sample is of 45 olive growing farms: 29 representing the rainfed system and 16 representing the irrigated system. These farms are from four different surfaces' strata (which represents the overall distribution of the farms in the study area): M_1: 0-5Ha, M_2: 5-10Ha, M_3: 10-50Ha, M_4: more than 50Ha (The samples are represented in the following proportions: M1: 26 %, M2:20 %, M3: 44% and M4: 10 %)

2.2. Estimation of virtual water in olive growing

For olive cultivation, virtual water corresponds to the total quantity of water used by this crop during one year to produce olives. This virtual water is drawn from the soil, which receives rainfall and possibly irrigation water. The calculation is based on FAO56 method (Allen *et al*., 1998; Souissi *et al*., 2013).

In this study, its estimation was undertaken in three steps:

- The estimation of the monthly water stocks (S_i) in the soil available for the crop.
- The estimation of the monthly Actual evapotranspiration (AET_i) of the crop.
- The estimation of virtual water used per unit of product obtained from the crop.

2.2.1. Estimation of monthly Si water stocks in soil available for cultivation

The water stock in soil S_i available at the end of each month i for cultivation is estimated using the following equation system:

$$S_i = \begin{cases} 0 & ; \ si S_{i-1} + EP_i + I_i - ETM_i \leq 0 \\ S_{i-1} + EP_i + I_i - ETM_i & ; \ si \ \ 0 < S_{i-1} + EP_i + I_i - ETM_i < UR \\ RU & ; \ si \ \ S_{i-1} + EP_i + I_i - ETM_i \end{cases} \quad (1)$$

Where:

- EP_i is the effective precipitation for the month i. $EP_i = c\ Pi$; with c = 0.8 and Pi: the total precipitation recorded during the month i;
- ETM_i is the maximum monthly crop evapotranspiration which represents the monthly water requirement of the crop during the month i. $ETM_i = Kc_i ETP_i$; with Kc_i: the crop coefficient during the month i and ETP_i: the potential evapotranspiration (or reference evapotranspiration ET_0) during month i;
- I_i is the amount of irrigation water brought to the crop during month i. In the case of a rainfed crop, $I_i = 0$ since irrigation is not applied.
- UR is the water storage capacity of the soil (useful reserve) which depends on the nature of the soil and the depth of rooting of the crop.

2.2.2. Estimation of the monthly Actual Evapotranspiration AET_i of the crop

The actual monthly evapotranspiration (AET_i) of the crop in month i is estimated using the equation system:

$$AET_i = \begin{cases} EP_i + I_i + S_{i-1} & si \ EP_i + I_i + S_{i-1} < ETM_i \\ ETM_i & si \ EP_i + I_i + S_{i-1} \geq ETM_i \end{cases} \quad (2)$$

Thus, the actual annual evapotranspiration (AET) which represents the total amount of water consumed by the crop (olive growing) during a year is given by the equation:

$$AET = \sum_{i=1}^{12} AET_i \quad (3)$$

If the crop is not irrigated, the I_i in equation (2) is zero and the actual annual evapotranspiration produced (equation 3) is denoted here by AET_p.

2.2.3. Estimation of the virtual water used per unit of product obtained from the crop

Virtual water VW (in m^3/Kg) is water consumed per Kg of agricultural product (olive) is estimated using the following equation:

$$VW = \frac{10\ AET}{R} \quad (4)$$

Where AET is in mm (multiplied by 10 we obtain the water consumption in m^3/Ha) and R, which represents the yield of the crop, is in Kg/Ha.

2.3. Estimation of the water footprint in olive growing

The water footprint is a spatial concept generally calculated at regional or country scales. In this study we use the spatial unit of Ha, as this unit can be subsequently extrapolated to larger scales, This, in order to measure the pressure of the use per Ha comparing two olive growing systems.

The olive growing water footprint is calculated based on the following equation:

$$WFP = VWXPt \quad \textbf{(5)}$$

Where:
WFP: water Footprint in m^3/Ha
VW: Virtual Water (water consumption/Kg of olive)
Pt: Olive yield (Kg/Ha)

2.4. Estimation of wasted irrigation water

The quantity of water irrigation wasted *Ig* is the volume of water given away by irrigation in addition to all the water consumed by the crop.
It can be estimated by the equation:

$$I_g = I - I_u \quad \textbf{(6)}$$

Where:
I is the total amount of irrigation water brought to the crop throughout the year

$$I = \sum_{i=1}^{n} I_i \quad \textbf{(7)}$$

And I_u is the quantity of irrigation water actually used by the crop during the year (**blue water**) and which represents the difference between the actual annual evapotranspiration in irrigated regime (AET) and the actual annual evapotranspiration under rainfed conditions (AET_p: **green water**).

$$I_u = AET - AET_p \quad \textbf{(8)}$$

2.5. Economic evaluation of water productivity

The economic evaluation of water used in olive growing in Medenine and Sfax, has been estimated through two indicators: biophysical water productivity expressed in Kg/m^3 and the economic water productivity in TD/m^3 which is the Gross Margin per m^3 of water consumed. Water consumed considered in this step is water consumption estimated in the previous section. These indicators will allow an economic evaluation of the biophysical and economic profitability of the water consumed by the plant (estimated in the previous step); leading to interesting conclusions while making comparisons between irrigated and rainfed olive growing systems and between the different groups of farms.

The implemented indicators are explained in the following equations:
Biophysical Water Productivity in Kg/m^3 (BWP_1) is obtained by the following formula:

$$BWP_1 = \frac{P}{Ev} \quad \textbf{(9)}$$

Where:
P: olive yield in Kg/Ha
VW: virtual water volume in m^3/Ha

Economic Water Productivity in TD / m^3 (*EWP_2*) is obtained by the following formula:

$$EWP_2 = \frac{GM}{PT} \quad \textbf{(10)}$$

Where:
GM: Gross Margin in TD/Ha = Incomes (TD/Ha) –Variable Costs (TD/Ha);
Revenue: is the multiplication of the Quantity Produced (Kg) of olive by the Unit Price of 1Kg of olive (TD)

NB: For each of the calculated parameters (volume of water, profitability in TD/m^3, Kg/m^3, TD/Ha), the weighted averages were estimated.

3. Results and Discussions

Results will be presented in two sections: i) the estimation of virtual water and the water footprint and their implications to explain hydric performances of the olive trees conducted in irrigated and rainfed modes. This, can shed light on the relevance of strategic choices of the country with regard to the extensions of the surfaces of olive tree in irrigated mode in Tunisia and at the same time on the adopted export policies; ii) the estimation of economic water productivity to focus on water use efficiency in different systems modes and different surfaces strata; and to focus on costs opportunity of olive from the irrigated and rainfed systems.

3.1. Virtual water and water footprint estimation

In irrigated farms, the weighted average volume of virtual water used is estimated at 1.15 m^3/Kg of olive, which represents a waste of irrigation water around 0.65 m^3/Kg. The farms that use less virtual water are those in the M_3 stratum that consume 0.71 m^3 to produce 1 Kg of olive compared to 1.3 m^3/Kg in the M_2 stratum; 1.69 m^3/Kg for the M_3 stratum and m^3/Kg for the M_4 stratum farms. These results clearly show that the farms in the M_3 stratum are the most efficient from the point of view of water management and control of the crop package. Indeed, the farms in the M_3 stratum are the farms that consume less water and produce the highest amounts of olive.

Olive production is on average 2.98 T/Ha for the M_3 stratum against 1.98 T/Ha for M_1; 1.86 T/Ha for farms in the M_2 stratum and 1.77 T/Ha for large-area farms in the M_4 stratum. The latter records the lowest production despite consuming the highest volume of virtual water (Table, 1). In the rainfed mode, the weighted average volume of virtual water used is of 1.61 m^3/Kg of olive. The farms of the M_3 stratum are still the most efficient producing even in rainfed the highest quantities of olive (1.22 T / Ha) against a virtual water consumption very close to the average. This area stratum (M_3) corresponds to the farms which size is between 10 Ha-50 Ha and are the most represented stratum at the level of the study area (about 44 % of the total farms' area). These farms represent a very important structural asset at regional level and represent the more specialized farms in the region (Table 1).

Whereas water foot print weighted average is estimated at 2668 m^3/Hain irrigated farms which represents a waste of irrigation water around 293 m^3/Ha. In the rainfed mode, the weighted average of water footprint in rainfed farms is around 1585 m^3/Ha. In relation with water footprint corresponding to each stratum we observe the same behaviour. In fact, the Stratum M_3 is the most efficient in term of water pressure in irrigated mode. Thus, the M_3 presents the less quantity consumed per Ha (2119 m^3/Ha) and an acceptable level of water wasted (58 m^3/Ha) comparing with weighted average (293 m^3/Ha). In reality, farms with surfaces from 10 Ha to 50 Ha are generally more specialized farms and with a more controlled technical package (Elfkih and Karray, 2011; Ben Abdallah *el al*., 2014; Ben Abdallah *et al*., 2022, Elfkih *et al*., 2022). In short, despite the pressure exerted on the water resource in irrigated mode, the values obtained in rainfed mode are higher in terms of virtual water. This is due to the low yields of the olive tree per hectare in this olive growing system. This makes the virtual water per Kg of olive a significant amount compared to irrigated mode. Therefore, it seems obvious that controlled irrigation water inputs and an adequate technical package can contribute to the improvement of the values of water consumed per Kg of olive produced (Ben Abdallah *et al*., 2014; Souissi *et al*., 2019; Ben Abdallah *et al*., 2021; Souissi *et al*., 2022).

Table 1. Virtual Water and Water Footprint in irrigated and rainfed olive growing in the study area

Olive Growing System	Farms' strata	Olive Yield (Kg/Ha)	Water Footprint WFP (m^3/Ha)	Wasted Irrigation Water per Ha-I_g (m^3/Ha)	Virtual Water VW (m^3/Kg)	Wasted Irrigation Water per Kg of olive-I_g (m^3/Kg)
Irrigated System	M_1	1982	3351	816	1.69	0.41
	M_2	1860	2419	14	1.3	0.01
	M_3	2984	2119	58	0.71	0.01
	M_4	1774	3319	578	1.87	0.32
	Weighted Average	**2320**	**2668**	**293**	**1.15**	**0.65**
Rainfed System	M_1	1025	2081	0	2.03	0
	M_2	830	1080	0	1.3	0
	M_3	1229	1586	0	1.29	0
	M_4	801	1667	0	2.08	0
	Weighted Average	**984**	**1585**	**0**	**1.61**	**0**

Source: Elaborated by authors from surveys

3.2. Economic Water Productivity

As explained above, economic water productivity is assessed based on two indicators: biophysical water productivity and economic water productivity. Others economic criteria (Incomes, Gross Margin and Production Costs) will be explained to draw significant conclusions.

In irrigated farms and concerning biophysical water productivity, 1m^3 of water consumed produces an average of 1.04 Kg of olive with an economic water productivity of 0.42 TD/m^3. The farms of the M_3 stratum have the best values of water productivity with an average of 1.4 Kg/m^3 and 0.51 TD/m^3, against 1.69 Kg/m^3 and 0.25 TD/m^3 for M_1; 0.59 Kg/m^3 and 0.25 TD/m^3 for M_2 and an average of 0.53 Kg/m^3 and 0.47 TD/m^3 for M_4 (Table 2).

In rainfed olive growing system, 1m^3 of water consumed produces an average of 0.65 Kg of olive which corresponds to an economic water productivity of an average of 0.37 TD/m^3. The farms with the highest water profitability in Kg/m^3 are those of the M_3 stratum followed by those of the M_2 stratum, then M_1 and in the last position the M_4 stratum. With regard to economic productivity, the most profitable farms in TD/m^3 are those in the M_2 stratum with an average of about 0.48 TD/m^3, followed by the M_3 stratum' farms with an average of 0.42 TD/m^3, then the M_4 stratum' farms with 0.32 TD/m^3, and finally the farms of the M_1 stratum (Table 2).

The comparison of the two olive growing systems (irrigated and rainfed) demonstrates a higher economic water productivity in irrigated farms (in terms of production and in terms of Incomes). It's very interesting to highlight the highest production costs associated with irrigated mode which significantly reduce the gap in benefits between irrigated and rainfed (Gross Margin). This makes it interesting to consider in the studied area the possibility of a complementary irrigation in the rainfed mode in the critical phase of the plant instead of a complete intensification of the system. This will allow an improvement in production without compromising many production factors and additional production costs (Elfkih *et al.*, 2022). This is not the case of farms of the stratum $M_{3\ \mathrm{in}}$ the irrigated mode where the production costs are the lowest and the benefits are the highest reflecting a more efficient use of production factors. It can also be seen that the farms in the M_3 stratum are the most efficient from a water management perspective since they consume less blue water and produce highest quantities of olives. In fact, good production is not only conditioned by the high supply of water but also by a full control of the cultural package and by the control of water doses proportionally with plant's needs (Ben Abdallah *et al.*, 2021; Ben Abdallah *et al.*, 2022).

Table 2. Economic profitability of the water used

Economic parameters	System	Farms' strata				Weighted average
		M1	M2	M3	M4	
Biophysical Water Productivity-BWP (Kg/m^3)	Rainfed	0.49	0.76	0.77	0.48	0.65
	Irrigated	1.69	0.59	1.4	0.53	1.04
Economic Water Productivity-EWP (TD/m^3)	Rain	0.24	0.48	0.42	0.32	0.37
	Irrigated	0.25	0.25	0.51	0.47	0.42
Revenue (TD/Ha)	Rain	839	812	1047	875	933
	Irrigated	1672	1399	2536	2049	2103
Production Costs(TD/Ha)	Rain	321	290	380	511	347
	Irrigated	834	794	1455	489	983
Gross Margin (TD/Ha)	Rain	518	522	667	364	586
	Irrigated	838	605	1081	1560	1120

Source: Elaborated by authors from surveys

The overall weighted average of virtual water in olive growing farms (rainfed and irrigated) in the study area (southern Tunisia) is about 1.38 m^3/Kg while this value is about 2.32 m^3/Kg of olive in the northern zone especially in the Zaghouan region (Souissi *et al*.,2013). In this same northern area, producing 1 Kg of soft wheat requires a virtual amount of water about 1.14 m^3 (Souissi *et al*., 2013; Souissi *et al*., 2019). These results highlight and reinforce the importance of strategic choices on crop allocation based on cost opportunity in order to achieve food security goals at the national level. Indeed, it seems more profitable in terms of water security and in terms of cost opportunity, to adapt strategic choices to climatic stage (Ben Abdallah *et al*., 2014; Souissi *et al*., 2019; Souissi *el al*., 2022).

4. Conclusions

In the regions of Sfax and Medenine, the different calculated indicators (Virtual water, water footprint and economic productivity) highlight the importance of a whole technical package and a controlled and efficient use of water in order to improve the profitability of olive cultivation. Certainly, the excessive supply of water can in no way lead to higher profitability on olive farms conducted on irrigated system, because of the high cost of production of this production system and because of the possible loss of water outside the period of high needs of the plant. However, a suitable combination of inputs with the full crop technical operations (pruning and tillage) is necessary to improve productivity. Indeed, generally the farms that provide controlled water doses accompanied with an adequate technical package are the most productive and the most economically profitable contributing therefore to a better management of the water resource.

In a structural point of view related with the distribution of farms by area stratum, the analysis shows clearly a strong relation between stratum's farms and economic performances. In this perspective is important to point out, the relevance of the stratum M_3 as the best representing the best water uses efficiency and the best economic and production factors uses. This stratum (medium to large: 10Ha – 50Ha), represents a category of farmers specialized generally with a full occupation in agriculture. In studied region this stratum' farms is the most efficient in terms of production and water management, which is a structural asset given the importance of the representivity of this stratum in the area studied.

This work has the originality to combine several sound indicators of water accounting (virtual water, water footprint and water productivity). These concepts were generally used separately in the most cases in the scientific literature in spite of the complementarity of their conceptions and the relevance of the conclusions that can be drawn from their integrated use. Water accounting and the study of its economic productivity is a fundamental step in understanding the success factors that can lead to good decision about food security especially in a context of water scarcity.

This study opens up a wealth of opportunities for further research. These include more in-depth: i) studies of the water accounting throughout the Tunisian olive oil value chain, ii) studying the same issues in several production systems, and finally iii) to study in depth the understanding of the technical and economic efficiency of the studied farms in relation with water use.

References

AgriDATA. 2019. Statistiques du Ministère de l'Agriculture. http://agridata.tn/.

Chapagain, A., Hoekstra, A. 2004. Water footprints of nations. (Value of Water Research Report Series; No. 16). Unesco-IHE Institute for Water Education.

Allan, J.A. 1993. Fortunately, there are substitutes for water otherwise our hydro-political futures would be impossible. *Priorities for water resources allocation and management.* ODA, 13-26. London (UK).

Allen, R.G., Pereira, L.S., Raes, D., Smith, M. 1998. Crop evapotranspiration: guidelines for computing crop water requirements, FAO Irrigation and Drainage Paper 56. United Nations Food and Agriculture Organization, Rome.

Ansorge, L. Stejskalová, L. 2022. Water Footprint as a Tool for Selection of Alternatives (Comments on "Food Recommendations for Reducing Water Footprint"). *Sustainability* 14, 6317. https://doi.org/10.3390/su14106317

Ben Abdallah, S., Elfkih, S., Ghzel, L., Souissi, A., Chbil, Ali., Frija, A., Istambouli, T., Mtimet, N., Abdelkafi, B.H., Ben Alaya, A. 2014. Evaluation de l'Eau Virtuelle en Aridoculture: Perspectives pour un Développement Durable dans les zones de Sfax, Mahdia et Médenine. *Revue des Régions Arides*, Numéro Spécial, n° 35 (3/2014) P: 2011-2015.

Ben Abdallah, S., Elfkih, S., Parras Lopez, C., Suárez-Rey, E.M., Romero-Gámez, M. 2021. Evaluation of the environmental sustainability in the olive growing systems in Tunisia. Journal of Cleaner Production. https://doi.org/10.1016/j.jclepro.2020.124526

Ben Abdallah, S., Parras Lopez, C., Elfkih, S., Suárez-Rey, E.M., Romero-Gámez, M. 2022.Sustainability assessment of traditional, intensive and highly-intensive olive growing systems in Tunisia by integrating Life Cycle and Multicriteria Decision analyses. *Sustainable Production and Consumption* 33: 73–87. https://doi.org/10.1016/j.spc.2022.06.022

Ben Boubaker, H., Benzarti, Z., Hénia, L. 2003. Les ressources en eau de la Tunisie : contraintes du climat et pression anthropique. Du livre « Eau et environnement » :37-52. ENS Editions.

D'Ambrosio, E., De Girolamo, A.M., Rulli, M.C. 2018. Assessing sustainability of agriculture through water footprint analysis and in-stream monitoring activities. *Journal of Cleaner Production* 200: 454-470. https://doi.org/10.1016/j.jclepro.2018.07.229

Dominguez, F. 2010. Can virtual water operators help. *Utilities Policy* 18: 129-134.

Elfkih, S., Karray, B. 2011. Les différentes structures de production de l'huile d'olive biologique dans la région de Sfax : une analyse comparative. Revue Ezzaitouna 12(1): 13 - 27.

Elfkih, S., Sahnoun, H., Ameur, W., Ben Abdallah, S., Albouchi, L. 2022. Organic olive growing farms' sustainability assessment: the Tunisian case. *EMJE* 7 : 565–581 https://doi.org/10.1007/s41207-022-00337-z

FAO. 2002. Crops and drops: making the best use of water for agriculture. 2002. Roma: FAO.

Fernández-Uclés, D., Elfkih, S., Mozas-Moral, A., Bernal-Jurado, E., Medina-Viruel, M.J., Ben Abdallah, S. 2020. Economic Efficiency in the Tunisian Olive Oil Sector. *Agriculture* 10, 391; doi:10.3390/agriculture10090391.

Gargouri, K., Bentaher, H., Rhouma, A. 2012, Novel method to assess drought stress of olive tree. Agronomy for Sustainable Development, Springer Verlag/EDP Sciences/INRA, 32 (3): 735-745.

Ghrab, M., Gargouri, K., Bentaher, H., Chartzoulakis, K., Ayadi M., Ben Mimoun, M., Masmoudi, M.M., Ben Mechlia, N., Psarras, G. 2013. Water relations and yield of olive tree (cv. Chemlali) in response to partial root-zone drying (PRD) irrigation technique and salinity under arid climate. *Agriculture Water Management* 123: 1-11.

Giordano, M., Rijsberman, F., Maria Saleth, R. 2006. More crop per drop: revisiting a research paradigm. London: IWA Publishing House.

Hamdane, A., Besbes, M., Chahed, J., Shayeb, H. 2013. L'eau en Tunisie. Political Science. https://doi.org/10.51257/a-v1-w3005

Hoekstra, A. Y. 2003. Virtual water trade. Proceedings of the International Expert Meeting on Virtual Water Trade, IHE Delft. Value of Water Research Report Series N°12 Delft, The Netherlands.

Hoekstra, A.Y., Hung, P.Q. 2005. Globalisation of water resources: international virtual water flows in relation to crop trade. *Global Environmental Change* 15: 45-56.

Letseku, V., Grové, B. 2022. Crop Water Productivity, Applied Water Productivity and Economic Decision Making. *Water* 14, 1598. https://doi.org/10.3390/w14101598

Lovarelli, D., Bacenetti, J., Fiala, M. 2016. Water Footprint of crop productions: A review. *Science of the total environment* 548-549: 236-251. https://doi.org/10.1016/j.scitotenv.2016.01.022

Novo, P., Garrido, A., Varela-Ortega, C. 2009. Are virtual water "flows" in Spanish grain trade consistent with relative water scarcity?. *Ecological Economics* 68 (5): 1454-1464.

ONAGRI. 2021. Données statistiques de l'Observatoire National de l'Agriculture. Ministère de l'Agriculture, des Ressources Hydrauliques et de la Pêche. Tunisie.

Scheierling, S., Treguer, D.O., Booker, J.B. 2016. Water Productivity in Agriculture: Looking for Water in the Agricultural Productivity and Efficiency Literature. *Water Economics and Policy* 2(3). 1650007. https://doi.org/10.1142/S2382624X16500077

Shirmohammadi-Aliakbarkhani, Z., Afshin, A. 2021. Investigation of economic analysis of water productivity in the most important crops of Torbat-e-Jam plain. *Singapore J. Sci. Res*. 11: 23-30.

Souissi, A., Ben Alaya, A., Abdelkefi, B.H., Stambouli, T., Ghzel, L., Belaid, R., Naceur, Y., Ousleti, M., Elfkih S., Ben Abdallah S. 2013. Contribution of virtual water to improving water security in Tunisia: Soft wheat *and olive trees in the Zaghouan region*. *Proceedings of the International Seminar*, *Sustainable Management of Water and Soil Resources: Situation, Challenges and Prospects.* Hammamet, Tunisia.

Souissi, A., Chebil, A., Mtimet, N. 2019. Virtual water flows and water value in Tunisia: The case of wheat and olive. *Arab J Geosci* 12: 421. https://doi.org/10.1007/s12517-019-4589-4

Souissi, A., Mtimet, N., McCann, L., Chebil, A., Thabet, C. 2022. Determinants of Food Consumption Water Footprint in the MENA Region: The Case of Tunisia. *Sustainability* 14(3):1539.

Sraïri, M.T., Assis, L., Kuper, M. 2021. Assessing physical and economic water productivity in crop-livestock systems. AFRIMED AJ – *Al Awamia* (133): 63-82.

Trabelsi, L., Gargouri, K., Ben Hassena, A., Ghrab, M. 2019. Impact of drought and salinity on olive water status and physiological performance in an arid climate. *Agricultural Water Management* 213: 749-759.

Triki, M. A., Hassaïri, A., Mahjoub, M. 2006. Premières observations de Verticillium dahliae sur olivier en Tunisie. *Bulletin OEPP/EPPO* 36: 69–71.

Van Halsema, G.E., Vincent, L. 2012. Efficiency and productivity terms for water management: a matter of contextual relativism versus general absolutism. *Agric. Water Manage*. 108: 9-15.

Xiao, J., Wei, J., Wu, M., Cao, X. 2022. Bibliometric and Visual Analysis of Crop Water Footprint: A Widely Used Agricultural Water Resources Evaluation Method. *Water* 14: 2866. https://doi.org/10.3390/w14182866

Yerli, C., Sahin, U. 2022. An assessment of the urban water footprint and blue water scarcity: A case study for Van (Turkey). *Brazilian Journal of Biology* 82, e249745 | https://doi.org/10.1590/1519-6984.249745

Zhang, C., Anadon, L.D. 2014. A multi-regional input–output analysis of domestic virtual water trade and provincial water footprint in China. *Ecological Economics* 100: 159-172.

Zhang, Y., Huang, K., Yu, Y., Yang, B. 2017. Mapping of water footprint research: A bibliometric analysis during 2006–2015. Journal of Cleaner Production 149: 70-79. https://doi.org/10.1016/j.jclepro.2017.02.067

Zhan-Ming, C., Chen, G.Q. 2013. Virtual water accounting for the globalized world economy: National water footprint and international virtual water trade. *Ecological Indicators* 28: 142-149.

Zho, N., Samson, E.L. 2012. Estimation of virtual water contained in international trade products using night time imagery. *International Journal of Applied Earth Observation and Geoinformation* 18: 243–250.

Appendix

Olive growing system and Stratum		Footprint water parameters and wasted irrigation				Virtual Water parametrs					Economic Parameters		
		AET (mm)	AET_p (mm)	I_u (m^3/Ha)	I (m^3/Ha)	I_g (m^3/Ha)	VW (m^3/Kg)	I_u (m^3/Kg)	AET_p (m^3/Kg)	I_g (m^3/Kg)	Olive yields Kg/Ha	Revenue (TD/Ha)	Gross Margin (TD/Ha)
Irrigated	M_1	335.1	154.2	1809	2625	816	1.69	0.91	0.78	0.41	1982	1672	838
	M_2	241.9	144.3	977	991	14	1.3	0.52	0.77	0.01	1860	1399	605
	M_3	211.9	135.5	763	821	58	0.71	0.25	0.45	0.01	2984	2536	1081
	M_4	331.9	174.7	1572	2150	578	1.87	0.88	0.98	0.32	1774	2049	1560
	Average	**266.8**	**150.7**	**1160**	1453	**293**	**1.15**	**0.5**	**1.15**	**0.65**	**2320**	2103	1120
Rainfed	M_1	208.1	208.1	0	0	0	2.03	0	2.03	0	1025	839	518
	M_2	108	108	0	0	0	1.3	0	1.3	0	830	812	522
	M_3	158.6	158.6	0	0	0	1.29	0	1.29	0	1229	1047	667
	M_4	166.7	166.7	0	0	0	2.08	0	2.08	0	801	875	364
	Average	**158.5**	**158.5**	0	0	**0**	**1.61**	**0**	**1.61**	**0**	**984**	933	586

Source: calculated by the authors based on surveys and CRDA Medenine and CRDA Sfax data basis 20

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