Research Article Open Access

Value of Virtual Water Applied for the Production of Strategic Agricultural Commodities of Tunisia

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Received
January 10, 2017

Accepted
March 25, 2017

Published Online
March 31, 2017

Abstract: The objective of this study is to estimate the virtual water content of strategic crops produced in Tunisia and to determine its economic value in the different bioclimatic areas of the country using the residual imputation method. A set of experiments and surveys were conducted for this purpose. Average values of virtual water embedded in the selected crops (including cereals, vegetables, and trees), varied from 0.38 Tunisian dinars (TND) m^{-3} to 1.3 TND m^{-3}. Moreover overall virtual water used by crops (including green and blue water) found to be more accurate for assessing and comparing water valorization among crops and agroclimatic zones of Tunisia.

Keywords: Virtual water, residual imputation method, agricultural commodities, agroecological zones, Tunisia.

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Cite this article as: Makhlouf, M., A. Chebil, A. Frija and A. Benalaya. 2017. **Value of virtual water applied for the production of strategic agricultural commodities of Tunisia.** Journal of Environmental and Agricultural Sciences. 10: 52-63.

1 Introduction

In the Mediterranean region, around 63% of total water consumption is used for agricultural activities (Fernandez, 2007). Water demand in the Mediterranean doubled during second half of the 20th century reaching 280 km^3 $year^{-1}$ and is expected to reach 330 km^3 $year^{-1}$ by 2025. This increase is mainly due to high population growth rate and increasing pressure on global water resources (Blue Plan, 2012). Despite some encouraging progress in terms of water use efficiency, losses during transfer, distribution and uses represent nearly 40% of total demand, which is equivalent to 100km^3 $year^{-1}$ (Blue Plan, 2012). Like most of the Middle East and North Africa (MENA) countries, Tunisia is facing serious water scarcity problems due to the high variability of precipitation (Chahed et al., 2015; El Kenawy et al., 2016; Funk et al., 2016; Sakhel et al., 2017; Sowers et al., 2011). During 2004-12 Tunisia received rainfall water at an annual average of 296 mm. There were spatial variations in annual rainfall. Maximum rainfall water was received in Northern parts of Tunisia reaching annual average of 1500 mm. However southern parts of country faced water scarcity with annual precipitation water of 100 mm (GDWR, 2012).

Numerous efforts were made to mobilize and enhance the capacity and supply of water resources. Considering water availability issues Tunisia had to modify its water policy on demand based water management approach (Chebil et al., 2012). The objective was to cope with water shortage and encourage rational and efficient use of available water resource. During the last three decades, water demand policies in Tunisia has known a progress either on the technical side through providing different incentives for the adoption of water saving technologies or on the regulatory side by designing different water pricing programs since the early 1990s (Chebil et al., 2012). Much research has been conducted to evaluate the effect of different demand management instruments and its achievement in terms of resource sustainability in Tunisia (Frija et al.,2009a; Frija et al., 2009b; Chemak, 2011; Chebil et al., 2012; Frija et al., 2014). However, only few studies where interested in assessing whether there was a shift in the economic valuation of water in parallel to the shift of the water management strategy (Chebil et al., 2011).

Economists have been using the concept of the economic value of water to assist policy makers in setting appropriate economic instruments for water demand management. These include irrigation water pricing, water quotas, subsidies of water saving technologies, devotion of management tasks to farmers associations, and others. While most studies were focusing on the attribution of economic value to blue water the current paper aims to define the scope of the economic dimension of virtual water (VW) concept for generating optimal use and allocation of the major agricultural commodities in Tunisia, through estimation of overall VW value. VW value will be assessed based on a database derived from field investigation including 80% of the country's regions and bioclimatic areas. In fact, the majority of studies evoking VW concept, quantified VW content and exanimate VW flows (Sun et al., 2013; Konar et al., 2013; Mekonnen and Hoekstra, 2014).

Previous studies on water value estimation in Tunisia essentially focused on irrigation water value (Chebil el al., 2011; Chouchane et al., 2015). Moreover, most of these studies were focusing on the blue water management and thus ignoring the green water used by the crops. In the context of water scarcity, the concept of VW might be more adequate and might open a new scope for the investigation of sustainably options of water resources. The concept of VW was first used in the literature during the mid-90s (Allan, 2003) to indicate the amount of water required for commodities production. During the last fifteen years, through VW quantification, several studies showed remarkable improvement in the public awareness regarding water scarcity and the need to promote national and international policies which might enhance water allocation among countries and regions (Hoekstra and Hung, 2002). Literature related to VW is mostly interested in estimating VW flows between countries and worldwide (Turton et al., 2000). However, in the existing literature, only few studies focused on the distinction between green and blue water (Aldaya et al., 2010; Chahed et al, .2015; Talozi et al., 2015; Antonelli et al., 2015; Fader et al.,2011). In Tunisia, Chahed et al. (2015) estimated the VW content of some agricultural production in rainfed and irrigated agriculture. The study of Antonelli et al. (2015) also highlighted the importance of green and blue VW flows in the MENA region, including Tunisia. Also, Fader et al.(2011) attempt to quantify green and blue internal and external water footprint using a general modeling at global-scale.Konar et al. (2013) used an economic model of trade and hydrologic model of agricultural water use in order to project global virtual water trade flows between nations for rice, soy and wheat.

This study aims mainly to separately estimate the green and blue VW content of strategic crops produced in Tunisia and to determine its economic value in different bioclimatic areas.

1.1. Virtual water concept

Allan (1998) defined VW as "the volume of water embedded in commodities that are traded internationally". The VW content of traded commodities is the amount of water consumed during the production of this good (Zimmer and Renault, 2003). In the case of agricultural products, VW is approximated by crop's evapotranspiration. Around 90% of virtual water trade worldwide comes from agricultural commodities exchanges (Blue Plan, 2008). In agricultural commodities VW content was mainly calculated for estimating VW flows between countries, by quantifying, for a given country, the water used for agricultural supply, exported, and imported commodities (Hoekstra and Hung, 2002; Zimmer and Renault, 2003; Chapagain and Hoekstra, 2006). Therefore, VW can primarily be applied as a water balance indicator for the countries where pressure on water resources is relatively high (Calderon, 2007) with clear indication on how such balance can be affected by different production, consumption, and trade aggregates. VW concept also helped to increase public awareness regarding water scarcity and promoted national and international policies that would positively influence water allocation (Hoekstra and Hung, 2002; Allan, 2003).

1.2 Agricultural water value

Current conditions of water scarcity require optimal allocation and development of water resources which might only be possible by having accurate measurements of water values in order to attribute appropriate pricing for different uses. In this regard, and since the early 90s, the United Nations was calling for the attribution of monetary value to water by considering it as an economic good (Koudstaal et al., 1992). This conceptualization has been developed further and led to the creation of significant economic tools for water management.

Water resources hold an economic value since it's a key component to human prosperity and wealth (Arbues et al., 2000; Nawaz et al., 2016). In the literature, the economic value of a good is related to its contribution to the human welfare. According to Ward (2002), water can have an economic value only if it supply is scarce compared to its demand. From an economic point of view, water value is defined as the amount that a rational water user is willing to pay (Ward, 2002) against a unit of water. This willingness to pay is depending on the marginal benefit this user is drawing from using water in his different activities (Aydogdu et al., 2016). However, the valuation of water resources remains a delicate task sometimes requiring non-market valuation methods. Generally, values attributed to water come from the estimation of the cost of collection and transport of this water to different end users (agricultural, municipal, industrial and tourism). However, the many losses and the environmental externalities and costs due to this collection and transport of water, in addition to the water subsides offered for some particular uses (considered as marginal economic activities) may lead to a biased estimation of the water value. In this case, non-market valuation methods became appropriate to correct this bias.

For the particular case of agricultural water use, according to Lange (2006), the valuation of agricultural water is based on the hypothesis that farmers will use water until a point where the net return obtained from an additional unit of water (marginal return of water, also called marginal water value) is equal to its cost. The estimation of this marginal water value can be conducted through various approaches depending on specific objectives (Young, 1996; Leyva, 2005). The first approach can be through estimation of water demand function of farms using different programming and econometric methods (Berbel, 2011; Mesa-Jorado, 2010; Frija et al., 2014). Residual imputation method (RIM) is an alternative computational method which has been used water is applied as subsidized irrigation is subsidized and thus not reflecting its real economic value (Speelman et al., 2011). This latest approach provides an assessment of the average water value as being used by farmers in specific context. It has been used by various organizations around the world due to its simplicity (Leyva, 2005). Schyns and Hoekstra (2014) highlighted the importance of assessment of the water footprint and economic water productivity over the period of 1996-2005 in formulating national water policy in Morocco. Berbel et al. (2011) assessed the value of water use in Guadalquivir River basin in Spain through this method. Speelman et al. (2011) have also employed the same method to calculate irrigation water value at small-scale irrigation schemes in South Africa. Al-Karablieh et al. (2012) also used the RIM to estimate the average value of irrigation water used in agriculture across crops in Jordan. Many other applications of RIM can be found in the literature (Kiprop et al., 2015; and Chebil et al. 2011). In most of these studies, authors provide an assessment of only the blue water applied to specific crops of focus. This represents a general feature of all studies and methods used to provide a valuation of agricultural water use. Mesa-Jorado (2010), proposed a water production function where crops yields are also related to their evapotranspiration, which allows for more accurate estimation of the whole water value, including the green water used by the crop.

2. Methodology

To calculate the VW value in this study, we adapted the RIM method used by Speelman et al. (2009). Our adapted RIM is based on three steps: (1) quantification of the VW content in the main strategic agricultural commodities of Tunisia; (2) estimation of crop yield growth through VW use, and (3) determining the average value of virtual water (AVVW) through economic data collected at farm level. Therefore, the originality of this approach can be summarized as follows: 1) First, a unique database has been collected through different experiments and farmers surveys in all regions of Tunisia. This database includes our own measurements of actual evapotranspiration (ETA) of different crops and regions of the country. While other studies have been using ETA provided by FAO estimations, this study consider more accurate national-wide measurements of these values based on farm trials. This database provides water demand per hectare per crop across the different regions and agroclimatic zone of the country. Using such type of data may provide the opportunity to enhance water valuation in Tunisia through comparison of the same crops cultivated in different bioclimatic areas. 2) A second innovation of this work is the consideration of both green and blue water used by the crops in the water valuation method. This is expected to provide more accurate measurements of the water value by crops and bioclimatic areas.

2.1 Virtual water estimate method

Calculations of VW amount used by some strategic crops in Tunisia, which is the actual crop evapotranspiration, are based on FAO56 method (Allen et al., 1998), as follows:

$$ETA_i = \begin{cases} \mathrm{P\hat{u}_i + I_i + S_{i-1} - S_i} \, if \, \mathrm{R\hat{u}_i + I_i + S_{i-1} - S_i < ETM_i} \\ \mathrm{ETM_i} \, if \, \mathrm{P\hat{u}_i + I_i + S_{i-1} - S_i \geq ETM_i} \end{cases} \quad [1]$$

Since the rainfall water is not totally used by crops, $P\hat{u}_i$ refers to the 'effective rainfall which is assumed to be equal to 80% of the total rainfall (green water), ETM_i denoted the monthly maximum evapotranspiration or the crop water requirements (CWRi). The CWR is calculated from multiplying the potential crop evapotranspiration ET_p by the crop coefficient Kc_i. I_i is the monthly amount of irrigation water given to the crop (blue water), in the case of a rainfed crop $I_i = 0$. S_{i-1} and S_i are the available water in the soil ate month i-1 and i, respectively. The annual ETA is defined then as the sum of the monthly ETA_i.

$$ETA = \sum ETA_i \quad [2]$$

2.2. Yield gain estimation method

To emphasize the impact of virtual water (ETA) use on crops yield growth, we used the methodology proposed by FAO (Doorenbos and Kassam, 1979). This methodology based on the estimation of maximum crops yield obtained by minimizing water loss. The following formula was used for this purpose:

$$(1 - Y_A/Y_M) = k_y * (1 - (ETA/ETM)) \quad [3]$$

Where Y_A and Y_M are the actual and estimated crops yield; and Ky is crop yield response factor.

The estimated gap yield will be defined as follow:

$$Y_A/Y_M = 1 - [k_y * (1 - (ETA/ETM))] \quad [4]$$

2.3. Residual Value Method

The assumptions underlying the residual imputation method are based on neoclassical economic theory: i) producers are maximize their profit, ii) the total product value can be assigned to each input, except of water, according to their respective marginal productivity (iii) it is assumed that the opportunity costs of non-water inputs are given by their market price. Based on these assumptions, and following Euler's theorem, the price of each input must be equal to its margin product. Respecting the competitive market conditions in which inputs are marketed and all farmers are optimizing their profit, the residual valuation assumes that the Total Production Value (TPV=P'∗Y) is equal to the opportunity cost of all inputs (Young, 2005).

$$TPV = \sum Q_i * P_i + Q_w * P_w \quad [5]$$

Where Py, Pi and Pw are respectively the price of output, non-water inputs and water; Y is the crop yield, Qi is the quantity of non-water inputs and Qw is the volume of water used in the production process. In our case, inputs are: labor, machinery, fertilizers, seeds, pesticides and water.

Table 1.Regions covered by the survey (Benalaya et al., 2015).

Region	Bioclimatic area	Governorates
1. NW	Humid Sub-Humid (HSH), Cold Semi-Arid (CSA), Hot Semi-Arid (HAS)	Béja, Bizerte, Seliana, Kef and Jendouba
2. NE	Humid Sub-Humid(HSH), Cold Semi-Arid (CSA), Hot Semi-Arid (HAS)	Ariana, Manouba Ben Arous and Nabeul
3. CW	Cold Semi-Arid (CSA), Hot Semi-Arid (HAS) Arid (A)	Zaghouan, SidiBouzid, Kasserine and Kairouan
4. CSE	Hot Semi-Arid (HAS), Arid (A)	Sousse, Monastir, Mahdia, Sfax, and Médenine
5. SW	Saharan (S).	Tozeur, Gafsa and Kebili

Young (2005) described that value of water obtained through the RIM is none other than the net income after all other relevant costs is accounted. The residual value obtained by subtracting the non-water input costs from total crop return may be the gross margin and can be interpreted as the maximum amount the farmer would pay for water and still cover the cost of production (Agudelo, 2001). This value, divided by the total water quantity used in production process, determines AVVW. When quantities and prices data of all inputs used are available, the estimated AVVW will be as follows:

$$WAV = (TVP - \sum Q_i * P_i)/Q_w \qquad [6]$$

2.4. Data Sources

For the empirical analysis, data used in this work, was collected within the framework of "Virtual Water and Food Security in Tunisia" project for the years 2012/2013. This database has been elaborated following a series of surveys that covered 21 governorates of Tunisia which have been aggregated into five regions (Northwest (NW), North East (NE), Central west (CW), Central and South-East (CSE) and Southwest (SW)), as shown in (Table I) (see Benalaya et al., 2015).

The survey included the main strategic crops (durum wheat, bread wheat, barley, olives, dates, almond, grape, citrus, apple, peach, potatoes, tomatoes and watermelon). It includes a representation of 67% of the total agricultural areas of Tunisia, and 78% of the total irrigated areas. We considered strategic crops as the crops which are important for both consumption and production (such as wheat, potato, tomato, major fruits, etc.). These crops are also mainly relevant for foreign trade and for their contribution to the total agricultural production in different regions (such as olive oil and dates). .Around 700 farms were randomly sampled considering their bio climatic area, farm type, and production system (rainfed and irrigated). The technical and economic data, obtained from the survey, included; i) a general crop description (type, variety, production system, bioclimatic area, etc.); ii) revenue (products and by-products); iii) operational costs of production (machinery, labor, fertilizer, pesticide, cost of water, transport, etc.); and, iv) description of water use(actual evapotranspiration, irrigation water, wasted water, etc). The VW considered in our case, is the annual evapotranspiration (ETA) which was measured separately for a sample of farms from the different considered regions. Other climatic data such as crop coefficient value (Kc) and crop yield response factor (Ky), were taken from FAO database. The potential crops evapotranspiration values (ETp) were taken from the database of the National Institute of Meteorology. Finally, obtained data were validated first at a regional level through round tables with technical staff from the Regional Commissions of Agricultural Development and then discussed and validated a second time through round tables with staff from the central Ministry of Agriculture and Hydraulic Resources of Tunisia.

3. Results

3.1. Quantification of virtual water for different crops and bioclimatic areas of Tunisia

At a national level, results show that the volume of VW embedded in the main crops produced in Tunisia depends on several factors, such as the production system (rainfed or irrigated), and the climatic variability among regions. The assessment of different volumes of water used by crops, shows that crops are receiving different combinations of green (rainfall) and blue (surface and ground) water depending on the regions and the availability of blue irrigation water. Considering the consumption of the supplied blue and green water, the considered fruit trees were found to be embedding much larger water compared to vegetables and cereals.

Among fruit trees, palm trees are the most water-intensive with an average consumption of 18597 m^3ha^{-1} of VW. For the rest of fruit trees, VW content varies from 3108 m^3ha^{-1} (olives under rainfed conditions) to 8351 m^3ha^{-1} (citrus under irrigated conditions). The calculated values of VW for the considered crops shows the existence of important gaps between received/applied and actual used water, which is interpreted as being a water loss. For instance, tomato is receiving about 6834 m^3ha^{-1} of blue and green water however its actual consumption (VW) is only 5663 m^3ha^{-1}which means an average water loss of 1171 m^3ha^{-1}.

Concerning green water contribution, Figure 1 illustrates a significant part of green VW content of grain crops which represents 80% of the total VW content. This high contribution of the green water in crop production is due to the fact that grains are cultivated in winter period.

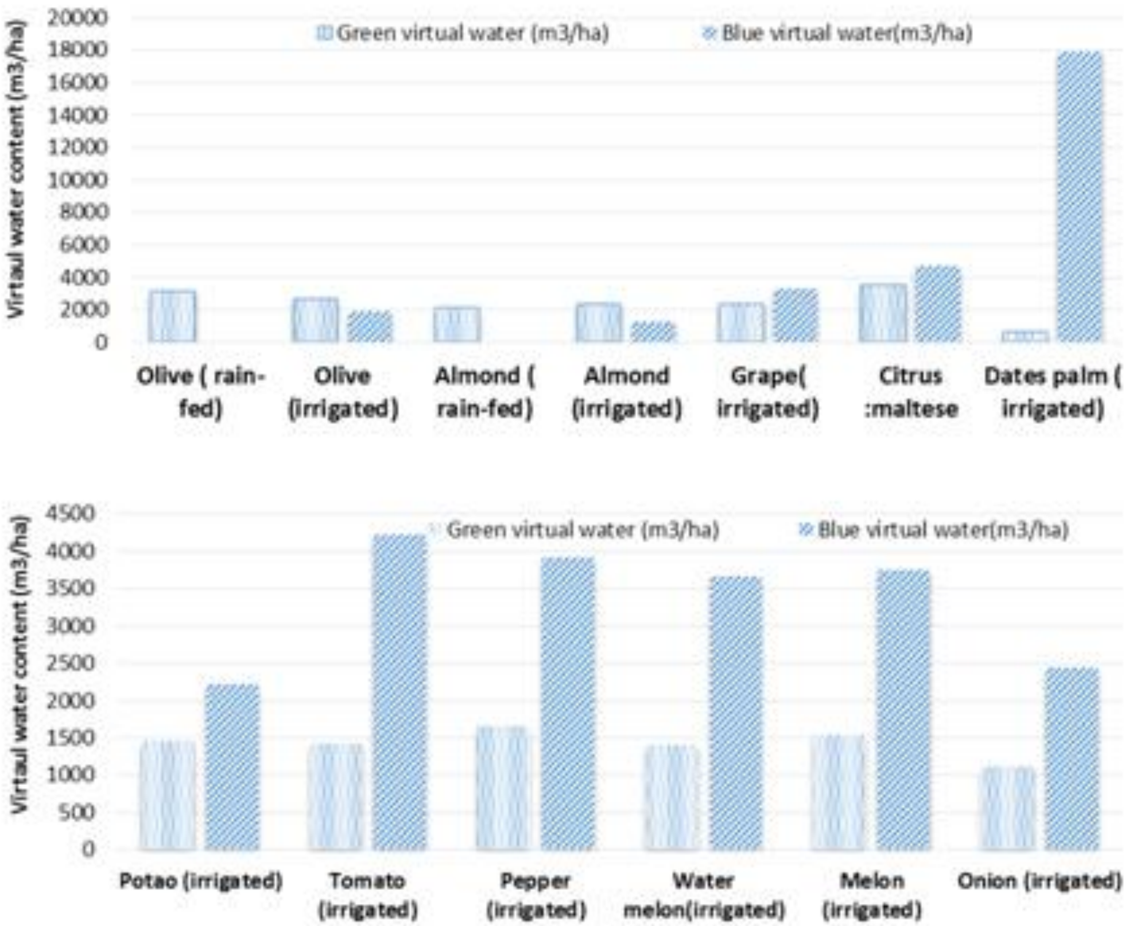

Fig. 1. Green and blue virtual water contribution

Nevertheless, regarding some fruit trees, as olives and almond which are mainly grown under rainfed condition, the part of green VW is higher than that of the blue VW (e.g., irrigated olive and almond consume respectively 2686 m^3ha^{-1} and 2344 m^3ha^{-1} of green VW against a volume of 1930 m^3ha^{-1} and 1242 $m^3ha^{-1}$of blue VW (Figure1). On the other hand, the rest of fruit trees such as citrus, grape, and dates, blue VW contributions exceeded 55% due to the high water requirement of these crops

By contrast to grain crops and fruit trees, green VW of vegetables represents around 30% of the total water content due to the highest water requirement of these crops cultivated in summer period. For instance, tomato consumes 4235 m^3ha^{-1} of blue VW, which represents 75% to the virtual water content of crop production, against 1428 m^3ha^{-1} of green VW.

Adequate use of these calculations of VW consumed by crops for policy design can lead to water saving and to higher water use efficiency. This is again showing that information about the VW content of crops should be used as one indicator among others for decision making about better water management.

Given the methodology proposed by the FAO (Steduto, 2012) to assess the crop yield response to water use, we attempt in this study to identify the impact considering the VW concept in water resource management. Water resources are not the only factor affecting agricultural yield. However, obtained results show that the use of appropriate water and the reduction of water waste may guarantee a crop yield growth. In fact, farmers growing potatoes and using 5166 $m^3ha^{-1}$of blue and green water are able to reach a crop yield up to 40.1 ton ha^{-1} instead of 22.7 ton ha^{-1} (Table 2) by using the amount of 1463 m^3ha^{-1} and 2219 m^3ha^{-1} of green VW and blue VW which refers to an important reduction of water waste.

Table 2.Yield increase due to virtual water uses

	Water supply (m^3 ha^{-1})	Virtual water (m^3 ha^{-1})	Observed yield (t ha^{-1})	Estimated yield (t ha^{-1})
Durum wheat (irrigated)	5116	4159	4.0	4.5
Durum wheat (rainfed)	4285	3428	2.5	2.8
Grapes (rainfed)	3395	2716	10.5	23.2
Grapes (irrigated)	5997	8053	37.0	51.4
Potatoes (irrigated)	5166	3682	22.7	40.1

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3.2. Virtual water value per crop, bioclimatic area

VW values are calculated for each crop and agroclimatic zone using the RIM approach, and based on the calculated average values of outputs and inputs for different crops (Table 3). In fact we found that irrigated crops usually hold higher Gross Margin (GM) compared to rainfed crops. This value, also considered as productivity indicator, depends essentially on the levels of outputs and inputs as well as their relative prices. Therefore, maximization of farm profitability requires an efficient allocation of all production factors, which will result, in turn, into higher values of natural resources used for the production process. For the specific Tunisian case, fruit trees, although consuming large volumes of water, are still having the highest GM (Table 3). For example, we found grapes and citrus have an average GM of 19110.6 TND ha^{-1}, and 12214.5 TND ha^{-1} respectively, which remained much higher than vegetables (e.g., 4530.8 TND ha-1 for Tomato) or cereals (e.g. 1584.1 TND ha^{-1} for durum wheat).

Table 3.Water value per crop

	Yield	Residual GM	Supplied water	GVW	BVW	Average values of		
						GVW	BVW	Supplied water
	(t ha^{-1})	(TND ha^{-1})	(m^3 ha^{-1})	(m^3 ha^{-1})	(m^3 ha^{-1})	(TNDm^{-3})	(TND m^{-3})	(TND m^{-3})
				Rainfed Condition				
Durum wheat	2.46	1021.4	3428	3428	_	0.30	_	0.3
Bread wheat	2.94	1003.8	3506	3506	_	0.29	_	0.29
Barley	2.23	597.3	3643	3643	_	0.16	_	0.16
Olive	1.94	923.2	3108	3108	_	0.30	_	0.3
Almond	0.55	1104.5	2134	2134	_	0.52	_	0.52
				Irrigation condition				
Durum wheat	3.97	1584.1	5116	2724	1435	0.58	1.10	0.31
Bread wheat	3.88	1474.7	6965	2895	2589	0.51	0.57	0.15
Barley	3.00	1165.2	4941	2966	945	0.39	1.23	0.24
Olive	3.28	1517.6	4682	2686	1930	0.56	0.79	0.32
Almond	1.9	2881.2	3740	2344	1242	1.23	2.32	0.77
Grapes	37	19110.6	5997	2379	3295	8.03	5.80	3.19
Citrus (thomson)	33.3	12214.5	9230	3506	4845	3.48	2.52	1.27
Dates	6.48	4584.2	21916	658	17939	6.97	0.26	0,2
Potatoe	22.68	4632.5	5166	1463	2219	3.17	2.09	0.99
Tomatos	65.31	4530.8	6834	1428	4235	3.17	1.07	0.66
Pepper	16.04	3053.7	4596	1657	3928	1.84	0.78	0.49
Water melon	33.97	3716.0	5519.4	1408.1	3665.7	2.64	1.01	0.54

Note: 1 Tunisian National Dinar (TND) = 0.55 US $ in 2012, * the residual represents the GM obtained by subtracting the non-water input costs from total annual crop return (Source: Authors calculations). GVW: green virtual water, BVW: blue virtual water

Based on GM values as well as on other costs and levels of VW use per ha measured for crops, Table 3 also presents average VW values as calculated by the RIM approach. Results show that; green VW in irrigated agriculture presents a higher average value (e.g., 0.39 TND m^{-3} for barley) comparing to green VW in rainfed agriculture (e.g., 0.16 TND m^{-3} for the same crop).

Regarding fruit trees, grapes hold the highest AVVW followed by citrus. For some fruit trees, the average value of blue VW is relatively higher than average value of green VW. For instance, olive production in irrigated area is valorizing blue VW at 0.79 TND m^{-3}(against an average value of 0.56 TND m^{-3} in rainfed area). However, this gap is essentially due to the low amount of blue VW used in these crops production. This is not the case for all tree crops where we noted that the average value of green VW is equal to 6.97 TND m^{-3} and 3.48 TND m^{-3} respectively for dates and citrus. This is also due to low contribution of green water in these crops production. Despite of the low average value of blue VW, it still more significant than the average value of brought irrigation water. For example, the use of 5997 m^3ha^{-1} for grape production generates an average value of 3.19 TND m^{-3}, however, the use of the appropriate amount of water (blue VW) generates an average value of 5.80 TND m^{-3}

Regarding vegetable crops, the highest AVVW is assigned to potatoes, with a value of3.17 TND per m^3 of green VW and 2.09 TND per m^3 of blue VW. On the other hand, the irrigated durum wheat presents a better value of water resource with average value of green VW equal to 0.58TND m^{-3}compared to common wheat and barley which means that it will be recommended to allocate water to durum wheat instead of common wheat or barley in order to increase the value of water used for cereal irrigation.

Average VW values of the same crops are found to be different among bioclimatic areas of Tunisia. For example, results are showing that potatoes grow in three bioclimatic areas of Tunisia. Results showed that the major crops valorizing water resource in "HSH" agroclimatic zone, are grapes grown in rainfed area, irrigated potatoes and irrigated tomatoes with an average value respectively equal to 4.63 TND m^{-3}, 1.26 TND m^{-3} and 0.78 TND m^{-3}.This means that, in order to guarantee a better water use efficiency, it will be more profitable to substitute barley and olives grown in rainfed areas, having an average water value of 0.18 TND m^{-3} and 0.26 TND m^{-3}respectively, by grape or potatoes(Table 4).

Regarding "CSA" bioclimatic area, major crops valorizing water resources are; grape, citrus, peach and potatoes grown in irrigated area with an average value respectively equal to 2.61 TND m^{-3} , 1.29 TND m^{-3}, 1.95 TND m^{-3} and 1.55 TND m^{-3}(Table 4). Based on these results, it will be recommended to encourage bread wheat and olive grown in rainfed area which present higher average water values (0.29 TND m^{-3} and 0.38 TND m^{-3} respectively) than the same crops grown in irrigated area (0.26 TND m^{-3} and 0.16 TND m^{-3}).

On the other hand, in order to reach a better water use efficiency and provide higher economic value in "HSA" bioclimatic area, it will also be recommended to encourage growing almond in rainfed areas (1.45 TND m^{-3}), irrigated almond (2.99 TND m^{-3}), irrigated apples (1.54 TND m^{-3}), irrigated peach (1.09 TND m^{-3}) and potatoes (1.28 TND m^{-3}). Nevertheless, in "Arid" bioclimatic area, expect irrigated grape and apples, most crops present an average value nearby 0.50 TND m^{-3}.

Table 4. Economic value of virtual water of crops in different agroclimatic zones (TND m^{-3})

	HSH	CSA	HSA	A	S
		Irrigated Condition			
Durum wheat	0.33	0.29	0.19	-	-
Bread wheat	0.32	0.29	0.17	-	-
Barley	0.18	0.16	0.17	-	-
Olive	0.26	0.38	0.26	0.48	-
Almond	-	0.22	1.45	0.95	-
Grapes	4.63	-	-	-	-
		Irrigated Condition			
Durum wheat	0.59	0.38	0.32	0.40	-
Bread wheat	-	0.26	-	-	-
Barley	0.37	0.30	0.24	-	-
Olive	-	0.16	0.39	0.44	-
Almond	-	0.33	2.99	-	-
Grapes	-	2.61	-	4.35	-
Citrus	0.51	1.29	0.88	-	-
Apple	-	0.65	1.54	1.58	-
Peach	-	1.95	1.09	-	-
Dates	-	-	-	-	0.24
Potaeos	1.26	1.55	1.28	0.56	-
Tomato	0.78	0.95	0.93	0.43	-
Water melon	0.40	0.75	0.95	0.62	-

HSH: humid sud-humid; CSA: cold semi-arid; HAS: hot semi-arid; A: arid; S: Saharan; Source: Author's Calculations

Therefore, it will be recommended to replace irrigated bread wheat, which has the lowest average value (0.40 TND m^{-3}), by other crops (almond grown in rainfed area for example) that provide higher economic value, while consuming similar or lower water volumes. Consequently, an analysis per agroclimatic zone may provide accurate insights about better strategies for the valorization of irrigation water in the agricultural sector of Tunisia.

4. Discussion

The first result of our study shows that cereals in Tunisia are embedding a higher volume of GVW compared to fruit trees and vegetable crops. These results are similar to other figures of VW content of some agricultural commodities in Jordan. In their study Talozi et al. (2015) indicated that fruits and vegetables, in Jordan, are produced respectively with 56% and 98% of blue water. Our results concerning the share of green VW are close to those obtained by Chouchane et al., (2015) and Chahed et al. (2015). Results from Chouchane et al. (2015)showed that the green VW contributions to the VW content of crop production exceeded 80% in the case of barley. In average, the obtained results of Chahed et al. (2015)show the importance (a share of three-quarters) of the green water contribution in the agricultural production in Tunisia.

According to Renaut (2003), VW highlights a new approach to sustainable management of water resources by the spatial reorientation of production. Therefore, VW concept might contribute to water saving and provide a new agricultural system. A practical example of such implication of VW quantification for our case study can be related to the benefit of substituting apples plantation by grapes in order to reduce water loss and enhance the water use efficiency. On the other hand, appropriate water use through better targeting of crops areas allocation based on their levels of VW content may enhance farmers' livelihood in parallel to ensuring better durability of the resource by reducing water losses. Furthermore, results show that the average value of water is different among crops and bioclimatic area. Commodities such as grape, citrus and potatoes are among the crops with higher AVVW in the studied regions. However, dates hold a lower AVVW (0.24 TND m^{-3}).The main reason of this low AVVW is related to the fact that dates consume high volumes of water. In fact, the high AVVW for fruit trees is mainly explained by their higher GM.

The obtained results in this study are similar to the irrigation water calculated in other studies using the same method for the Africa (Speelman et al., 2009; Kiprop et al., 2015; Schyns and Hoekstra, 2014) and Tunisian (Chebil et al., 2011;Chouchane et al., 2015) contexts. For instance, Spleeman et al. (2009) reported that the average value of irrigation water is about 0.45 TNDm^{-3}(0.23 US\$ m^{-3}) for tomatoes in South Africa ;in our study we found an average value of irrigation water equal to 0.66TND$m^{-3}$for the same crop in Tunisia. Schyns and Hoekstra (2014), also reported that the economic value of water for dates is about 0.5 TNDm^{-3} (0.2US\$$m^{-3}$ in Morocco which a little higher than the average value founded in our study (0.2TNDm^{-3}). On the other hand, our results show similar figures of average value of blue VW to these of Chouchane et al. (2015), where they found that the average value of blue VW is higher than the average value of green VW in the case of irrigated wheat in the period 1996-2005.The comparison of VW content and value among crops in different bioclimatic areas of Tunisia might be highly useful for policy makers to investigate the possibility to promote specific crops in specific areas. Such a policy can be considered within the overall set of water demand management instruments adopted by the Tunisian government, and may in turn promote better allocation of water resource and enhance its durability. Crops should in fact be promoted in bioclimatic areas where they are consuming the least of VW, and recording the less of water losses. Therefore, estimating the values of VW for the strategic crops produced in Tunisia provides an opportunity for a new mapping of agricultural systems and for enhanced reallocation of water resources.

5. Conclusion and policy implications

This paper investigates the potential of considering virtual water concept as a new alternative for water demand management, through i) quantification and comparison of the level of virtual water for crops in different bioclimatic areas of Tunisia; and ii) by providing some guidelines for better water allocations through optimized cropping patterns based on their respective average virtual water value in order to improve the water use efficiency and alleviate water pressure. Our results show that fruit trees and vegetables valorize better the water resource compared to cereals. That's to say that one cubic meter used for fruit trees and vegetables may provide respectively a gain of 1.35TND and 0.83TND in the farmers gross margin returns against a low gain of 0.28 TND per cubic meter for cereals. From an economic point of view, in order to improve water use efficiency, it will be advantageous to encourage farmers to invest more in fruit trees instead of cereals. However, cereals are strategic crops which we cannot marginalize. It will be recommended then to utilize the concept of virtual water to determine irrigation requirements in order to improve crop yields and therefore financial returns. Finally, analysis of the obtained results may lead to water policies implications. To face water shortage, government has to take the initiative to help farmers improving their welfare and preserve water resource for the next generations. Then, government must i) improve farmer's awareness about water shortage issue; ii) attribute subsidies for crops holding a high economic value or tax the high intensive water crops and iii) enhance farmer's capacity development through a better control of water efficient techniques.

Acknowledgements: Authors acknowledge the support of International Development Research Centre (IDRC) for funding this research under Grant "number 106545 – 001". This research was supported by the IDRC 'project "Virtual water and Virtual Food Security"; led by the Higher School of Agriculture Mograne.

Competing Interest: The authors declare that there is no potential conflict of interest.

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