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The water footprint of Tunisia from an economic perspective

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ABSTRACT

This paper quantifies and analyses the water footprint of Tunisia at national and sub-national level, assessing green, blue and grey water footprints for the period 1996–2005. It also assesses economic water and land productivities related to crop production for irrigated and rain-fed agriculture, and water scarcity. The water footprint of crop production gave the largest contribution (87%) to the total national water footprint. At national level, tomatoes and potatoes were the main crops with relatively high economic water productivity, while olives and barley were the main crops with relatively low productivity. In terms of economic land productivity, oranges had the highest productivity and barley the lowest. South Tunisia had the lowest economic water and land productivities. Economic land productivity was found to explain more of the current production patterns than economic water productivity, which may imply opportunities for water saving. The total blue water footprint of crop production represented 31% of the total renewable blue water resources, which means that Tunisia as a whole experienced significant water scarcity. The blue water footprint on groundwater represented 62% of the total renewable groundwater resources, which means that the country faced severe water scarcity related to groundwater.

1. Introduction

As one of the most arid countries in the Mediterranean, Tunisia suffers from high water scarcity. The shortage of water resources is a limiting factor to food production. Generally, water resources use is reported per economic sector, without explicitly indicating the precise purpose of water use. For instance, in the agricultural sector, the largest water-using sector in Tunisia, it is unusual to look at specific water use per type of crop. It is important to do so, however, in order to be able to assess the economic productivity of water use. In this paper, we apply the water footprint concept to address the issue of economic water productivity.

The water footprint (WF), introduced by Hoekstra (2003) as a comprehensive indicator of freshwater use, quantifies and maps water consumption and pollution in relation to production or consumption. The WF has three components: blue, green and grey (Hoekstra et al., 2011). The blue WF refers to consumption of blue water resources (surface and groundwater). The green WF refers to consumption of green water resources (rainwater). The grey WF measures water pollution and is defined as the volume of fresh water that is required to assimilate the load of pollutants given natural background concentrations and existing ambient water quality standards. The WF of a crop is generally expressed in terms of m^3/tonne or l/kg, but can also be expressed in terms of m^3 per monetary unit (Hoekstra et al., 2011). Garrido et al. (2010) show the usefulness of doing so in a case study for Spain. Mekonnen and Hoekstra (2014) show this for the case of Kenya, and Schyns and Hoekstra (2014) for the case of Morocco. Garrido et al. (2010) show that water scarcity affects water productivity; users become more efficient in their blue water use as water becomes scarcer, but this behavioural adaptation only occurs in regions where water is scarce and where blue water is the main contribution to total crop water use.

A concept closely related to WF is water productivity (WP). The increasing scarcity of fresh water and the important role that water plays in food production impose the need to optimise water use in all human activities, particularly in agriculture, the main water-using sector worldwide. There is no common definition of the term WP (Rodrigues and Pereira, 2009), but in all definitions WP refers to the ratio of the net benefits from crop, forestry, fishery, livestock or mixed agriculture systems to the amount of water used to produce those benefits. Physical WP can be defined as the ratio of agricultural output to the amount of water consumed ('crop per drop'), which is mostly expressed in either blue water withdrawal or total (green plus blue) water consumption through evapotranspiration (Kijne et al., 2003; Zwart and Bastiaanssen, 2004, 2007; Playan and Matoes, 2006; Molden, 2007). When water use is measured as green plus blue water consumption, physical WP (in tonne/m^3) is thus an inverse of the green plus blue WF (in m^3/tonne).

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Table 1
Water scarcity thresholds.

Blue water scarcity levels*	Water scarcity thresholds
Low blue water scarcity	<20%
Moderate blue water scarcity	20–30%
Significant blue water scarcity	30–40%
Severe water scarcity	>40%

* Water scarcity is defined as blue water footprint/renewable blue water resources.

Expressing WP in physical terms does not give insight in the economic benefit of water use; therefore, it is useful to consider economic water productivity (EWP) as well (Cook et al., 2006; Pereira et al., 2009). EWP is defined as the value derived per unit of water used, i.e. 'dollar per drop' (Igbadun et al., 2006; Palanisami et al., 2006; Teixeira et al., 2008; Vazifedoust et al., 2008; Garrido et al., 2010). The scope for increasing the value per unit of water used in agriculture is often bigger than the scope for increasing physical WP (Molden et al., 2010).

In this paper we quantify and analyse the green, blue and grey WF within Tunisia, analyse the blue WF in the context of blue water availability and assess economic water and land productivities related to crop production for irrigated and rain-fed agriculture. The period of analysis is 1996–2005. The study adds to earlier WF studies for Tunisia (Chapagain and Hoekstra, 2004; Chahed et al., 2008, 2011; Mekonnen and Hoekstra, 2011a; Hoekstra and Mekonnen, 2012) by putting emphasis on the analysis of the economic dimension of water use. The study focuses on the WF of production within Tunisia, rather than the WF of Tunisian consumption. The latter is partly located outside Tunisia. The external WF of Tunisian consumption is about 32% of the total WF of national consumption (Mekonnen and Hoekstra, 2011a); the current paper does not address this external WF. Furthermore, the study focuses on the WF of the crop sector, because this sector accounts for 87% of the total WF of production in the country (Mekonnen and Hoekstra, 2011a).

2. Methods and data

The study follows the terminology and methodology as set out in *The Water Footprint Assessment Manual* (Hoekstra et al., 2011), which contains the global standard for Water Footprint Assessment (WFA). We will put the blue WF of Tunisian production in the context of renewable blue water resources in order to assess water scarcity. Vörösmarty et al. (2000), Alcamo and Henrichs (2002), and Oki and Kanae (2006) consider a country to be severely water stressed if the ratio of blue water withdrawal to renewable blue water resources (runoff) is higher than 40%. Here, we define water scarcity based on blue water *consumption* (blue WF) rather than blue water *withdrawal*, which is more meaningful, because a significant share of withdrawn water returns to rivers and aquifers and becomes available for reuse (Hoekstra et al., 2012). We thus compare the blue WF to renewable blue water resources. Table 1 shows the water scarcity thresholds used in this study, equivalent to the thresholds used by Hoekstra et al. (2012). We calculate overall water scarcity on annual basis as the ratio of total blue WF to total renewable blue water resources, and groundwater scarcity as the ratio of the blue WF from groundwater sources to renewable groundwater resources.

In calculating water productivities, we distinguish between rain-fed and irrigated agriculture. Rain-fed agriculture only consumes rainwater, so that we can speak of green WP. In the case of irrigated agriculture, we distinguish between green and blue WP, because both rainwater and irrigation water are consumed. In irrigated agriculture, green WP is defined as the yield that would be obtained based on rain only (assuming no irrigation) divided by the volume of green water consumed. Blue WP is defined as the additional yield obtained through irrigation divided by the volume of blue water (irrigation water) consumed (Hoekstra, 2013).

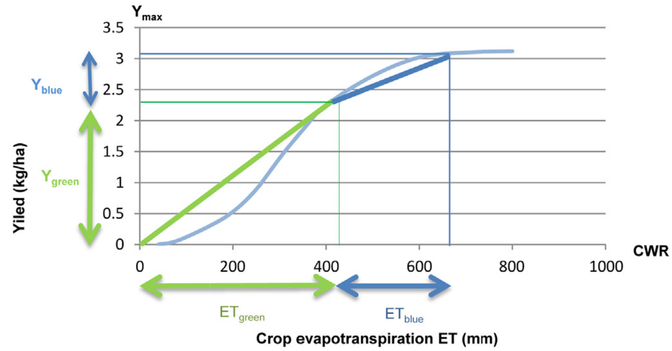

Fig. 1. The relation between yield and evapotranspiration from a crop field. Green and blue water productivities appear as the slopes of each of the two line segments drawn in the graph. (For interpretation of the references to color in the text citation of this figure, the reader is referred to the web version of this article.)

The yield obtained from rain only is estimated based on the equation proposed by Doorenbos and Kassam (1979):

$$\left(1-\frac{Y_a}{Y_m}\right)=K_y\left(1-\frac{\mathrm{ET}_a}{\mathrm{CWR}}\right) \quad (1)$$

where K_y is a yield response factor (water stress coefficient), Y_a the actual yield (kg/ha), Y_m the maximum yield, obtained under optimal water supply conditions (kg/ha), ET_a the actual crop evapotranspiration (mm/period) and CWR the crop water requirement (mm/period). Following this equation, the green-water based yield ($Y_{\mathrm{green,irrig}}$) in irrigated agriculture can be calculated from:

$$\left(1-\frac{Y_{\mathrm{green,irrig}}}{Y_{\mathrm{tot,irrig}}}\right)=K_y\left(1-\frac{\mathrm{ET_{green}}}{\mathrm{ET_{green}}+\mathrm{ET_{blue}}}\right) \quad (2)$$

whereby $Y_{\mathrm{tot,irrig}}$ is the yield occurring under full irrigation (rain + irrigation water), which equals the maximum yield Y_m; $\mathrm{ET_{green}}$ is the evapotranspiration of green water that would have occurred without irrigation; $\mathrm{ET_{blue}}$ is the evapotranspiration of blue water. Data on $Y_{\mathrm{tot,irrig}}$, $\mathrm{ET_{green}}$, $\mathrm{ET_{blue}}$ and K_y are obtained for all irrigated crop areas from the grid-based study of Mekonnen and Hoekstra (2010). The additional yield through irrigation is calculated as the total yield in irrigated agriculture ($Y_{\mathrm{tot,irrig}}$) minus the yield that would be obtained without irrigation ($Y_{\mathrm{green,irrig}}$).

Fig. 1 shows the relation between yield and evapotranspiration during the growing period and visualises green and blue WP through two subsequent slopes. The first (green) slope represents the green WP, while the second (blue) slope represents the blue WP.

Economic water productivities (US$/m^3) are calculated by multiplying physical water productivities (kg/m^3) by crop value (US$/kg). Similarly, economic land productivities (US$/ha) are calculated by multiplying yields by crop value. For a farmer, blue EWP may be a relevant variable for production decisions, as blue water use goes along with direct production costs or blue water availability may be limiting production. Land productivity may influence decisions on crop choices if land availability is the most limiting factor for a farmer.

The study is based on data for the period 1996–2005. Table 2 gives an overview of all input variables and data sources used in this study. We divided the country into three regions based on climate: North, Central and South (Fig. 2). North has a Mediterranean climate, South has a Sahara climate, while Central has a climate in between. Each region consists of governorates, administrative sub-units.

Table 2
Overview of input variables and data sources used.

Input variable	Source
Water footprint of crop production	Mekonnen and Hoekstra (2010, 2011b)
Water footprint in other sectors	Mekonnen and Hoekstra (2011a)
Yields and evapotranspiration in rain-fed and irrigated systems	Mekonnen and Hoekstra (2010)
Water resources availability and water withdrawal at national level	Ministry of Environment (2009)
Surface water availability and withdrawal at regional level	Ministry of Agriculture (2005a)
Groundwater availability and withdrawal at regional level	Ministry of Agriculture (2005b)
Crop values (producer prices)	FAOSTAT (FAO, 2009)

3. Results

3.1. Water footprint of national production

The total water footprint (WF) of Tunisian production was about 19 billion m^3 (Gm^3) per year (89% green, 8% blue, 3% grey) over the period 1996–2005. The WF of crop production gave the largest contribution to the total WF of production (87%), followed by grazing (11%). The remaining part (2%) represented domestic water supply, livestock production and industrial activities (Mekonnen and Hoekstra, 2011a).

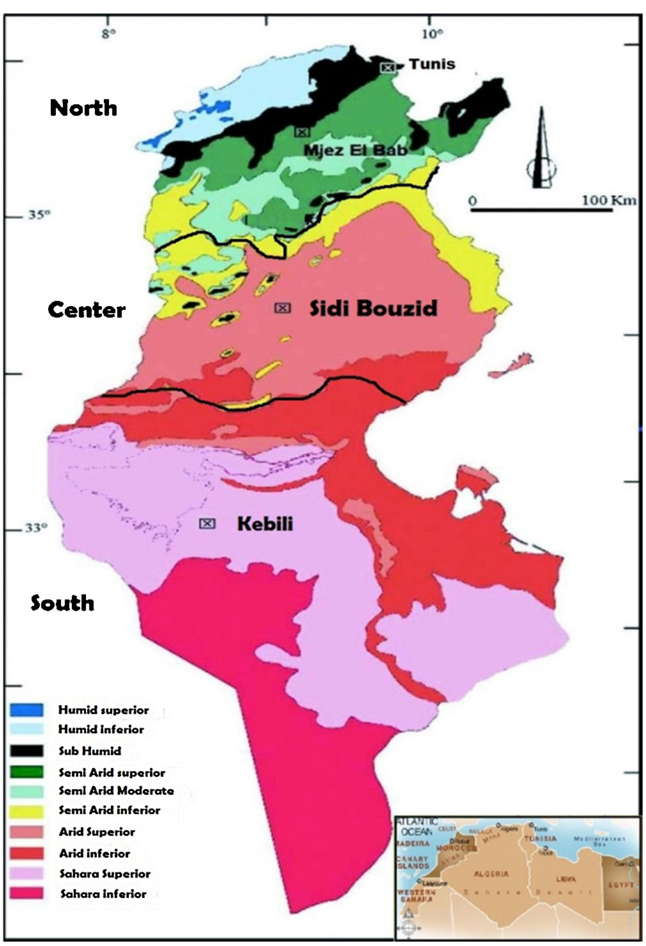

Fig. 2. Bioclimatic map of Tunisia. Source: Chelbi et al. (2009).

The WFs of the main crops are listed in Table 3. The listed crops represent 86% of the total blue WF of crop production. Among these crops, almonds had the largest WF per unit of weight, about 20820 m^3/tonne, which is more than twice the global average WF for almonds. Tunisian almonds used about four times more green water than the global average, while they consumed about the global average amount of blue water. Tomatoes had the smallest WF of 120 m^3/tonne, which is below the global average (210 m^3/tonne). Dates, almonds, figs and grapes were the biggest blue water users with 3270, 1950, 1740 and 1080 m^3/tonne respectively. These figures are higher than the global averages, especially for grapes, which used ten times the global average amount of blue water.

Olives alone accounted for about 46% of the total WF of crop production in Tunisia. About 79% of the total green WF was due to the production of olives (7.3 Gm^3/year), wheat (3.2 Gm^3/year) and barley (1.2 Gm^3/year). The total blue WF was dominated by dates and olives (together 47%) and, to a lesser extent by grapes, wheat and almonds.

3.2. Water footprint of crop production at sub-national level

The total WF of crop production in Tunisia was about 16.6 Gm^3/year (89% green, 8% blue, 3% grey). North Tunisia took the biggest share in the total WF of crop production (70%), followed by Central (26%) and South (4%) (Table 4; Fig. 3). Regarding blue water, North Tunisia had the biggest share in the total blue WF, with 0.65 Gm^3/year, which represents 49% of the total blue WF of crop production in the country. South and Central Tunisia followed with 28% and 23% respectively. In South Tunisia, the driest part of the country, the total WF of crop production was dominated by blue water (with a contribution of 68%).

Table 4 shows the WF per unit of weight for the most important crops, for each of the three regions. The difference in WFs and crop water requirements in North and Central is not so big, but the values in South differ considerably, especially for olives, wheat, almonds, figs and barley. In terms of the blue WF, a unit of wheat or barley grown in South Tunisia used almost twelve times more blue water than the same crop grown in North, largely because irrigation is the dominant production system in South, whereas rain-fed production is dominant in Central and North. Almond and figs grown in Central Tunisia used less blue water than in the other regions, while tomatoes and carrots grown in South Tunisia had the smallest blue WF per tonne.

3.3. Blue water footprint of crop production in the context of blue water availability

Tunisia has limited blue water resources, estimated at 4.87 Gm^3/year in 2005, of which 4.26 Gm^3/year are renewable (Ministry of Environment, 2009). The remaining part, 0.61 Gm^3/year, is fossil groundwater situated in South Tunisia, and expected to be exhausted in about 50 years at the current extraction rate (FAO, 2003).

The total renewable surface water (TRSW) was estimated at 2.70 Gm^3/year (Table 5). This amount represents the average calculated over a 50-year period. Surface water contributions come from four distinct natural regions. The far northern part of North Tunisia, with only 3% of the total Tunisian land area, has on average about 0.96 Gm^3/year of TRSW, which is about 36% of the national total. The basins of Majerda and Melian in North Tunisia provide an average of 1.23 Gm^3/year (45% of the national total). Central Tunisia, including the watersheds Nebhana, Marguellil, Zeroud and Sahel, has an average TRSW of 0.32 Gm^3/year (12%). South Tunisia, which represents about 62% of the total national land area, has very irregularly available surface water resources, averaging 0.19 Gm^3/year, or 7% of the national TRSW (Ministry of Environment, 2009).

Table 3
The average green, blue and grey water footprint of main crops and total water footprint of crop production in Tunisia (1996–2005).

Crop	Total water footprint (Mm³/year)				Water footprint per tonne of crop (m³/tonne)				Global average water footprint (m³/tonne)			
	Green	Blue	Grey	Total	Green	Blue	Grey	Total	Green	Blue	Grey	Total
Almonds	790	90	50	930	17760	1950	1110	20820	4630	1910	1510	8050
Barley	1220	30	60	1310	3560	80	180	3820	1210	80	130	1420
Carrots	10	30	2	40	260	530	30	820	110	30	60	200
Dates	110	350	10	470	1030	3270	80	4390	930	1250	100	2280
Figs	70	40	4	120	2810	1740	170	4720	1500	1540	280	3280
Grapes	70	130	10	200	550	1080	60	1690	430	100	90	610
Olives	7270	270	30	7570	8790	330	40	9150	2470	500	50	3010
Oranges	40	20	2	70	370	230	20	620	400	110	50	560
Potatoes	40	40	10	80	110	120	20	260	190	30	60	290
Tomatoes	50	40	10	100	60	50	10	120	110	60	40	210
Wheat	3170	100	150	3420	2380	70	110	2560	1280	340	210	1830
Other crops	1980	190	112	2290								
Total	14820	1330	450	16600								

Source: Mekonnen and Hoekstra (2011a). Note that tonne refers to metric tonne.

Table 4
The average green, blue and grey water footprint and crop water requirement of main crops in Tunisia per region (1996–2005).

Crop	Water footprint per tonne of crop (m³/tonne)				Total water footprint (Mm³/year)				Crop water requirement (m³/ha)
	Green	Blue	Grey	Total	Green	Blue	Grey	Total	
North									
Almonds	16590	2480	1010	20090	380	60	20	460	9220
Barley	3520	90	180	3790	930	10	50	990	4570
Carrots	290	500	40	820	10	20	1	30	6340
Dates	–	–	–	–	–	–	–	–	–
Figs	2840	1680	170	4690	60	40	4	110	7780
Grapes	780	1120	70	1970	30	40	3	70	7160
Olives	8650	400	40	9080	4660	170	20	4850	8150
Oranges	370	220	20	610	40	20	2	60	7780
Potatoes	130	110	20	260	30	40	10	70	3550
Tomatoes	70	40	10	120	40	30	10	70	3510
Wheat	2360	90	110	2550	2820	70	130	3020	4980
Other crops					1650	150	90	1910	
Total					10650	650	340	11640	
Centre									
Almonds	18290	1490	1200	20980	410	30	30	470	9550
Barley	3470	240	200	3910	290	10	20	320	4710
Carrots	490	380	70	940	3	7	0	10	6650
Dates	–	–	–	–	–	–	–	–	–
Figs	3460	1200	220	4880	10	10	1	10	8030
Grapes	700	1300	70	2060	30	50	3	90	7510
Olives	8840	470	40	9350	2580	100	10	2690	8420
Oranges	370	240	20	630	3	3	0	10	8020
Potatoes	110	130	20	270	10	20	0	40	3660
Tomatoes	80	40	10	120	10	10	2	20	3640
Wheat	2350	230	120	2710	350	20	20	390	5120
Other crops					300	30	10	340	
Total					4000	290	100	4390	
South									
Almonds	20810	2330	2080	25220	10	1	1	10	11780
Barley	3770	1050	310	5130	2	1	0	3	6070
Carrots	670	30	150	860	0	0	0	0	7760
Dates	1040	3290	80	4390	110	350	10	470	13350
Figs	4940	820	500	6260	0	0	0	0	9920
Grapes	450	1870	70	2380	10	30	1	40	8730
Olives	10750	930	80	11760	30	3	0	40	10390
Oranges	210	510	30	750	0	0	0	0	9480
Potatoes	70	210	30	310	0	0	0	0	4310
Tomatoes	150	1	20	170	0	0	0	0	4500
Wheat	2780	1230	210	4220	3	1	0	4	6610
Other crops					0	4	0	4	
Total					160	390	10	560	

Source: Mekonnen and Hoekstra (2011b).

Table 5
Blue water footprint of crop production in the context of blue water availability.

	Blue water footprint (Mm^3/year)			Blue water resources (Mm^3/year)					Water scarcity (%)[e]	
	Ground-water[a]	Surface water[a]	Total [b]	Renewable blue water resources			Fossil[d]	Total	Ground-water	Overall
				Ground-water[d]	Surface water[c]	Total				
North	320	330	650	680	2190	2870		2870	47	23
Central	270	20	290	570	320	890		890	47	32
South	380	10	390	310	190	500	610	1110	123	78
Total	970	360	1330	1560	2700	4260	610	4870	62	31

Sources:
[a] Based on WF data from Mekonnen and Hoekstra (2011b) and ratios of surface water withdrawal to groundwater withdrawal per region from Ministry of Agriculture (2005a,b). Using the surface/groundwater ratios for withdrawals for estimating the surface/groundwater ratios for blue WFs implicitly assumes that the fractions of return flow are similar for surface and groundwater abstractions.
[b] Mekonnen and Hoekstra (2011b).
[c] Ministry of Environment (2009).
[d] Ministry of Agriculture (2005b).
[e] Own elaboration.

The total groundwater resources are estimated at 2.17 Gm^3/year in 2005 (Ministry of Environment, 2009), of which 0.75 Gm^3/year are from shallow aquifers (depth less than 50 m) and 1.42 Gm^3/year from deep aquifers (deeper than 50 m) of which 0.61 Gm^3/year are non-renewable. The total renewable groundwater is thus 1.56 Gm^3/year. North Tunisia has 50% of the shallow aquifer resources; Central Tunisia contains 33%, while South contains 17%. Regarding deep aquifers, South has the biggest share (55%), followed by Central (23%) and North (22%).

In 2005, the total freshwater withdrawal in Tunisia reached 2.65 Gm^3/year, consisting of 0.70 Gm^3/year surface water withdrawal and 1.95 Gm^3/year groundwater withdrawal (Ministry of Environment, 2009). Not all abstracted water evaporates, so that part of the water used remains available in the country for reuse. When we want to compare water use to available water resources, it is better to compare the consumptive water use, i.e. the blue WF, to the available water resources. On a national scale, the total blue WF of crop production was 1.33 Gm^3/year, or 31% of total renewable blue water resources of about 4.26 Gm^3/year. This means that Tunisia experienced ‘significant water scarcity’ according to international standards. Note that in this analysis we include only the blue WF related to crop production, but this contributes 93% to the total blue WF in the country, so we slightly underestimate water scarcity.

It is estimated that, at national scale, 73% of the blue WF of crop production relates to groundwater consumption, while 27% refers to surface water consumption. The blue WF that specifically relates to groundwater consumption represented 62% of the total renewable groundwater resources, which means that the country was facing severe water scarcity related to groundwater (Table 5).

At the regional level, the highest overall water scarcity occurred in South Tunisia (severe scarcity of 78%), followed by Central (significant scarcity of 32%) and North (moderate water scarcity of 23%). In terms of groundwater, all regions of the country experienced severe water scarcity, with a scarcity of 47% in both North and Central and 123% in South Tunisia, where consumptive groundwater use exceeded the available renewable groundwater.

The water scarcity figures presented here are calculated on an annual rather than a monthly basis. As noted by Hoekstra et al. (2012), this may lead to an underestimation of scarcity as experienced in the drier parts of the year, particularly because of the variability in available surface water resources within the year. For estimating groundwater scarcity, the annual approach will generally suffice because of the relatively long residence time and buffering capacity of groundwater systems. Groundwater scarcity figures are possibly underestimated, though, because return flows in groundwater-based irrigation are here assumed to return to the groundwater system from which abstraction took place, while part of the return flow may not return.

3.4. Economic water and land productivity at national level

An analysis of water management in a Mediterranean country must have a focus on irrigated agriculture (Garrido et al., 2010). Although irrigated land accounts to only 7% of the total cultivated land in Tunisia (Chahed et al., 2008), it contributes more than 35% to the total production of the agricultural sector and accounts for more than 80% of the total water withdrawal in the country (Ministry of Environment, 2009).

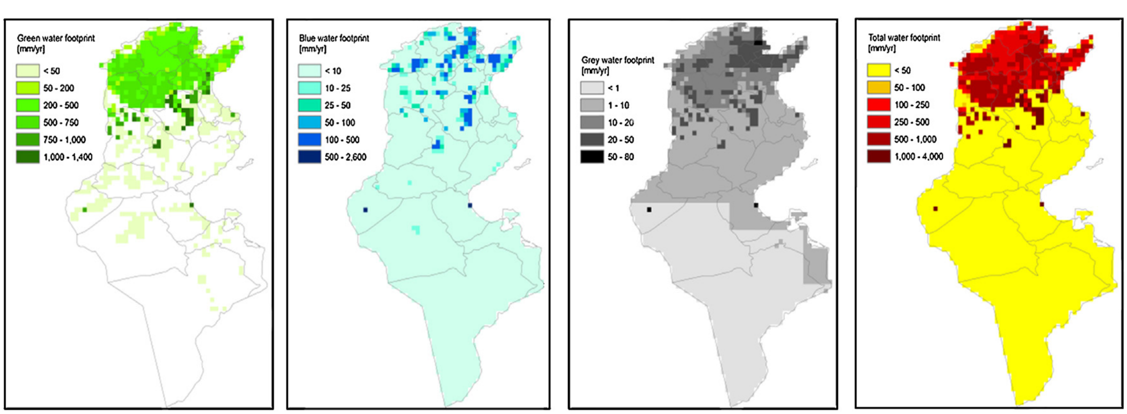

Fig. 3. The green, blue, grey and total water footprints of crop production in Tunisia. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Based on producer prices, Table 6 presents the economic water productivity (EWP) and economic land productivity (ELP) of main crops in Tunisia, for both rain-fed and irrigated agriculture. In the case of irrigated agriculture, we distinguish between green and blue EWP and ELP.

In terms of EWP, the average EWP in Tunisian crop production for the listed crops was around 0.32 US$/m^3, which is slightly less than the figure found in a study for Spain by Garrido et al. (2010), who found an average value of around 0.25 €/m^3, which is equivalent to about 0.35 US$/m^3. The average EWP in Tunisian rain-fed agriculture (0.35 US$/m^3) was somewhat higher than for irrigated agriculture (0.32 US$/m^3). For several of the selected crops, EWP in rain-fed and irrigated production systems were very similar. In the case of carrots and potatoes, however, total EWP was larger in irrigated agriculture than in rain-fed agriculture. For dates and tomatoes, we found the reverse.

In irrigated agriculture, the blue water applied was not always more productive than the green water. For carrots, potatoes and tomatoes, blue EWP in irrigated agriculture was found to be higher than green EWP, but for dates and grapes the reverse was found. While most of the blue water in Tunisia was consumed in dates, grapes, olives and wheat production (Table 3), the blue EWP of these crops was low when compared to potatoes and tomatoes, which had the highest blue EWPs, with 0.97 and 1.13 US$/m^3 respectively.

In terms of total ELP, oranges, tomatoes and dates had the highest values, with 4040, 3770 and 3080 US$/ha respectively, while barley and olives had lowest values, with 130 and 170 US$/ha respectively.

ELP was higher in irrigated agriculture than in rain-fed agriculture for all selected crops. Given the fact that, on average, EWP in irrigated agriculture was *not* higher than in rain-fed agriculture, one can conclude that irrigation water is generally not applied to increase EWP (US$/m^3) but rather to increase ELP (US$/ha). Enlarging the irrigated area for the listed crops will increase ELP. But, since water is a limiting factor in production, it would be most beneficial to increase irrigated areas only for crops with high EWP and for which the difference between ELP in rain-fed and irrigated agriculture is considerable, like, for example, potatoes.

Dates and oranges had relatively low EWP (0.23 and 0.58 US$/m^3 respectively) as compared to potatoes (0.87 US$/m^3), but the ELPs for dates and oranges were higher (3080 and 4040 US$/ha respectively) than the ELP for potatoes (2870 US$/ha).

At a national level, EWP figures provide little basis for understanding or explaining current cropping patterns. ELP figures give a better basis, because various crops with large production volumes (especially tomatoes, potatoes, oranges and dates) have a relatively high ELP. The main exceptions are wheat, barley and olives, having large production volumes but low ELP (and also low EWP).

3.5. Economic water and land productivity at sub-national level

Table 7 shows EWP and ELP for the main crops at regional level. North and Central Tunisia had similar EWPs. South Tunisia had lower EWPs for the listed crops except for potatoes. North Tunisia had the highest ELP for all listed crops except for carrots, grapes and tomatoes. Central Tunisia had the highest ELP for carrots and tomatoes, while Central and South had similar ELP for grapes. South had the lowest ELP for all crops except for dates and grapes.

When comparing rain-fed and irrigated agriculture, we find that the ELP of irrigated lands was much higher than the ELP of rain-fed lands for all listed crops. In South Tunisia, which is much drier than North and Central, the blue-water based ELP in irrigated agriculture was higher for all crops than in North and Central, which illustrates the greater importance of irrigation water to yields in the South.

Our conclusion at the national level is valid at regional level as well: enlarging irrigation areas will generally increase ELP,

Table 6
Economic water and land productivities of main crops in Tunisia at national level (1996–2005).

Crop	Economic water productivity (US$/m^3)					Economic land productivity (US$/ha)				
	Total (green) EWP in rain-fed agric.	Green EWP in irrigated agric.	Blue EWP in irrigated agric.	Total EWP in irrigated agric.	Average EWP in irrigated & rain-fed agric.	ELP in rain-fed agric.	Green-water based ELP in irrigated agric.	Blue-water based ELP in irrigated agric.	ELP in irrigated agric.	Average ELP in irrigated & rain-fed agric.
Almonds	0.09	0.09	0.09	0.09	0.09	390	380	440	820	430
Barley	0.04	0.03	0.04	0.04	0.04	130	90	90	180	130
Carrots	0.14	0.13	0.19	0.17	0.17	320	270	800	1070	1030
Dates	0.40	0.62	0.11	0.23	0.23	1210	1210	1890	3100	3080
Figs	0.10	0.10	0.10	0.10	0.10	460	442	370	810	720
Grapes	–	0.25	0.17	0.20	0.20	1040	650	830	1480	1480
Olives	0.03	0.03	0.03	0.03	0.03	160	150	130	280	170
Oranges	0.58	0.58	0.58	0.58	0.58	2610	2460	2060	4520	4040
Potatoes	0.80	0.77	0.97	0.88	0.87	1390	1200	1920	3120	2870
Tomatoes	1.26	1.03	1.13	1.07	1.08	2600	1990	1850	3840	3770
Wheat	0.10	0.09	0.12	0.10	0.10	370	290	240	530	370

Source: Own elaboration.

Table 7
Economic water and land productivities of main crops in Tunisia at regional level (1996–2005).

Crop	Economic water productivity (US$/m^3)					Economic land productivity (US$/ha)				
	Total (green) WP in rain-fed agric.	Green WP in irrigated agric.	Blue WP in irrigated agric.	Total WP in irrigated agric.	Average WP in irrigated & rain-fed agric.	ELP in rain-fed agric.	Green-water based ELP in irrigated agric.	Blue-water based ELP in irrigated agric.	ELP in irrigated agric.	Average ELP in irrigated & rain-fed agric.
North										
Almonds	0.09	0.09	0.09	0.09	0.09	410	390	420	810	460
Barley	0.04	0.03	0.05	0.04	0.04	130	90	90	180	130
Carrots	0.14	0.14	0.19	0.17	0.17	320	270	790	1070	1020
Date	–	–	–	–	–	–	–	–	–	–
Figs	0.10	0.10	0.10	0.10	0.10	470	450	360	810	740
Grapes	–	0.26	0.18	0.21	0.21	1040	710	760	1470	1470
Olives	0.03	0.03	0.03	0.03	0.03	160	160	120	280	170
Oranges	0.58	0.58	0.58	0.58	0.58	2580	2490	2030	4510	4090
Potatoes	0.80	0.77	0.97	0.88	0.88	1430	1220	1900	3120	2910
Tomatoes	1.25	1.03	1.13	1.08	1.09	2750	2050	1790	3840	3750
Wheat	0.10	0.10	0.12	0.10	0.10	360	300	220	530	380
Central										
Almonds	0.08	0.09	0.09	0.09	0.09	370	350	470	820	410
Barley	0.04	0.03	0.04	0.04	0.04	110	80	90	180	120
Carrots	0.13	0.13	0.18	0.17	0.17	290	240	840	1070	1060
Dates	–	–	–	–	–	–	–	–	–	–
Figs	0.10	0.10	0.10	0.10	0.10	430	400	420	810	670
Grapes	–	0.25	0.17	0.19	0.19	–	680	810	1480	1480
Olives	0.03	0.03	0.03	0.03	0.03	150	150	140	280	160
Oranges	0.58	0.58	0.58	0.58	0.58	2390	2200	2330	4530	4040
Potatoes	0.80	0.73	0.97	0.88	0.88	1280	990	2120	3110	2870
Tomatoes	1.28	1.02	1.13	1.08	1.08	2710	1820	2030	3840	3830
Wheat	0.09	0.09	0.12	0.10	0.09	310	250	270	520	340
South										
Almonds	0.07	0.07	0.07	0.07	0.07	210	190	630	820	230
Barley	0.03	0.06	0.02	0.03	0.03	60	100	70	170	80
Carrots	0.14	0.14	0.19	0.17	0.17	220	280	800	1080	970
Dates	0.40	0.62	0.11	0.23	0.23	1210	1210	1890	3100	3080
Figs	0.08	0.08	0.08	0.08	0.08	210	190	620	810	240
Grapes	–	0.37	0.13	0.17	0.17	–	620	860	1480	1480
Olives	0.03	0.03	0.03	0.03	0.03	70	80	210	280	80
Oranges	0.50	0.48	0.48	0.48	0.48	1110	1000	3520	4520	3360
Potatoes	0.81	0.77	1.00	0.91	0.89	630	1050	2080	3120	2510
Tomatoes	1.01	0.70	0.89	0.85	1.01	1330	720	3100	3820	1330
Wheat	0.04	0.05	0.09	0.08	0.07	100	90	440	520	190

Source: Own elaboration.

particularly in the South. But primarily in the South, water availability is the key limiting factor in production, not land availability, so optimising EWP is more advisable than optimising ELP.

Authorities in Tunisia are using volumetric water pricing systems for irrigation water. There is regional variation of irrigation water prices in Tunisia, from 0.02 to 0.08 US$/m^3 (Frija et al., 2014; Chebil et al., 2010). Blue EWP was around or below the price paid by farmers in various regions, especially for cereals (0.02 to 0.05 US$/m^3 for barley) and olives (0.03 US$/m^3). This supports Frija et al. (2014), who found, in a study on wheat durum in Central Tunisia, that in 50% of the farms the price of one additional cubic metre of irrigation water exceeds the benefit of that additional water.

For South Tunisia it is especially attractive to grow dates, because the climate and growing conditions are very suitable for this crop; dates are not grown in North and Central. The ELP for dates was high as well, but the EWP was not. From the perspective of economic water resources use in South, it is more attractive to grow potatoes, tomatoes and oranges than to grow dates.

The study of economic water and land productivity has a number of limitations that are mostly due to a lack of data. First, we assumed a single producer price of crops for all Tunisian regions, where differences can affect results at regional level. Second, we did not distinguish between prices for rain-fed and irrigated crops. Irrigated crops may have a higher price due to better quality, which would translate into a higher EWP and ELP in irrigated agriculture. Third, we calculated EWP and ELP by multiplying physical productivity and price, instead of the value added per unit of production, implying an overestimation of EWP and ELP. Fourth, we estimated EWP and ELP based on commodity prices, which may not reflect the full costs of those commodities. Finally, we assumed full irrigation in irrigated agriculture, while in reality irrigation may be limited.

4. Conclusions

The WF of Tunisian production was 19 Gm^3/year in the period 1996–2005. Green water had the biggest contribution (89%), but there are regional differences. Crops in South generally had a larger total WF and larger blue water fraction than in Central and North Tunisia, caused by differences in climate. South Tunisia is an arid region, explaining why the WF in this region was dominantly blue.

The country suffered significant water scarcity, with a national blue WF of crop production amounting to 31% of the country's renewable blue water resources. South Tunisia experienced severe water scarcity, Central Tunisia significant scarcity and North Tunisia moderate scarcity. For groundwater, all three regions experienced severe water scarcity, with the worst situation in South, where the blue WF resting on groundwater exceeded renewable groundwater resources by an estimated 23%.

91% of the total blue WF of the major crops in the country related to crops produced at blue EWPs below 0.20 US$/m^3. Only tomatoes, potatoes and oranges showed larger blue EWP. The smallest blue EWP is found for olives (0.03 US$/m^3), one of the major export products of the country.

Among the major crops grown in Tunisia, oranges, tomatoes and potatoes had relatively large EWP and ELP. The same, but to a lesser extent, is true for dates, grown in South only. Relatively low EWP and ELP values are found for wheat, barley, almonds, olives and figs. Irrigation generally increased ELP (US$/ha), but not EWP (US$/m^3). The contribution of blue water to ELP was largest in the dry South.

The scarce Tunisian water resources have mainly been allocated to uses with low EWP; this could be the result of the agricultural policy followed by the Tunisian government. Over the last forty years, Tunisia's agricultural policy focussed on ensuring food security by encouraging the production of staple crops, olive oil and livestock products. This policy intended to ensure prices for those products below international market prices (Ministry of Agriculture, 2002). In general, national agricultural policies, laid down in consecutive socio-economic development plans before and after the 2010 revolution, did not change considerably (Ministry of Agriculture, 2013). Tunisian authorities have started to re-think agricultural policy in relation to water resources management, but no real change in policy can be observed yet. By the end of 1999, Tunisia signed a free trade agreement with the EU, encouraging agricultural imports (Ministry of Agriculture, 2002). Where market conditions exist and staple foods may be externally supplied, farmers can be encouraged to shift to high-value crops and increase EWP (FAO, 2012).

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