Chapter 10

Lessons learnt from analyses of the water footprint of tomatoes and olive oil in Spain

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ABSTRACT: This chapter evaluates the water footprint (WF) of Spanish tomatoes and olive oil over the period 1997–2008. It analyses the three types of water: green, blue and grey. Water apparent productivity (WAP) and virtual water exports for tomatoes and olive oil have been studied. The ranges of the WF of tomatoes and olives per unit of product (m^3/t) show that providing a unique value for a product WF may be a strong assumption because of the widely different climatic conditions, production systems, productivity levels and irrigation schedules across the country. The greenhouse tomato system presents the greatest WAP, which is influenced by the much higher price of off-season productions and larger crop yield. However, tomato production also shows a high grey WF, implying a pressure over water resources related to nitrogen pollution. The increase of groundwater consumption in the upstream Guadalquivir basin caused concerns about the sustainability of olive irrigation. Recently, the situation seems to be under control given the deficit irrigation practices and the constraints imposed by the sharp increase in energy prices. The virtual water related to olive oil exports illustrates still the importance of the green water footprint of rainfed olives amounting to about 77% of the total virtual water exports.

Keywords: water productivity, groundwater, irrigation, sustainability, virtual water

1 INTRODUCTION

Spain is the largest world producer and exporter of olive oil and table olives. In the 2009/2010 agricultural season, nearly 50% of the estimated olive oil world production was produced in Spain, with 56% of Spanish olive oil intended for export. In this season olive oil production amounted to 1.4 Mt [Mt = million tonnes = 10^9 kg] and almost 2,000 M€ in 2.3 Mha [Mha = million hectares = 10^6 ha] (IOC, 2012; MARM, 2012). Over the period 1995–2009, olive production comprised in economic terms about 13% of the gross national agricultural production (MARM, 2012). During the same period tomatoes had a yearly average production of about 4 Mt from 61,000 ha. In economic terms, tomato production represented approximately 5% of the gross national agricultural production (MARM, 2012). In the 2009/2010 season 15% of tomatoes produced (4.8 Mt) were exported, though the period 1998–2009 showed an average of 25% for exports (MARM, 2012; DataComex, 2012).

Because of the economic and social importance of olive and tomato production in Spain, this chapter analyses the water footprint (WF) of green water (stored in the soil profile), blue (freshwater) and grey water (an indicator of pollutant assimilation capacity, see Glossary) for tomatoes and olive oil. The analysis is set from the Extended Water Footprint (EWF) perspective, which combines the contribution of the WF relying on water resources accounting (Hoekstra *et al*., 2011) with an economic perspective based primarily on determining the economic value of water (Garrido *et al*., 2010; see Chapter 6).

The innovations of this chapter in relation to previous studies are:

– Three growing systems for tomatoes (irrigated open air/greenhouses and rainfed) were distinguished. In addition, four yearly seasons (spring short, spring-summer, short autumn and long periods) were considered in greenhouse tomato production.
– It was assumed that olive orchards do not meet their irrigation water requirements. Irrigation water was restricted yearly based on level of drought.
– The grey WF for both crops was calculated based on nitrogen surplus instead of the nitrogen doses rate per hectare times the leaching fraction.

The following sections synthesize the main findings of two studies elaborated by the Water Observatory of the Botín Foundation (Chico *et al*., 2010; Salmoral *et al*., 2011), where more detailed information on data, applied methodology and references can be found.

2 METHODOLOGY OF THE WATER FOOTPRINT FOR TOMATOES AND OLIVE OIL

The green, blue and grey water components of tomatoes and bottled olive oil were calculated in absolute (volume) and relative terms (volume/unit of product) for the time period 1997–2008. We used the CROPWAT model to estimate the green and blue WF of both tomatoes and olive fruits in terms of evapotranspiration. For tomatoes, a distinction was made between growing systems (open air/covered irrigated and rainfed) and production cycle throughout the year (spring short, spring-summer, short autumn and long periods). Under irrigated conditions we assumed that the tomato crop water demand is completely satisfied and that irrigation was applied regularly on regardless of rainfall.

For olive fruit, irrigated versus rainfed systems were analyzed. It was assumed that the crop water requirements were not met. In the Guadalquivir basin water allowances vary from 1,200 to 2,500 m^3/ha in olives, the large figure corresponding to high density olive tree plantations; but this information is not from the public domain. As a result, we took a water allowance of 2,280 m^3/ha for a normal climatic year that was reduced annually according to the level of drought in the basin. The WF of olive oil as a product was calculated by dividing the olives water consumption by a product fraction of 20%, which indicates the quantity of olive oil obtained per kilogram of olives. The WF of one litre of bottled olive oil also required assessment of the water embedded in the bottle, cap and label. However, we did not quantify the WF of the production process of olive oil since the amount required on this step is insignificant as previous studies have shown (Avraamides & Fatta, 2008).

The grey WF is defined as the volume of freshwater that is required to assimilate a load of pollutants based on the natural concentration of pollutants in a receiving water body and the existing ambient water quality standards (see Hoekstra *et al.*, 2011; Glossary). An ambient water quality standard of 50 mg/L NO_3^- was used following the European Nitrates and Groundwater Directives. The natural concentration of pollutants in the receiving water body was assumed to be negligible. The grey WF was calculated for nitrogen since it is a very dynamic element which can be the source of diffuse pollution caused by leaching (See Chapter 12). Improvements in this study are achieved since the grey WF is calculated based on nitrogen surplus from the Spanish Agricultural Nutrient Balances (MARM, 2008) instead of the fertilizer application rate per hectare times the leaching fraction, which previous studies have used (Chapagain & Hoekstra, 2011; Mekonnen & Hoekstra, 2010; 2011a).

The water apparent productivity (WAP) and virtual water exports calculations for both tomatoes and olive oil were also assessed. Further details on the applied methodology can be found in Chico *et al.* (2010) and Salmoral *et al.* (2011).

3 RESULTS

3.1 The water footprint of tomatoes

Over the period 1997–2008 the green water ranged from 15 to 25 hm^3/year [hm^3 = cubic hectometre = million m^3 = 10^6 m^3] and the blue water varied between 250 and 460 hm^3/year. The lower green component in comparison to the blue one is because crop water requirements were fully meet. CROPWAT firstly evapotranspirates water from irrigation than water from rain when both events occur on the same day. The national grey WF varied from 470 to 710 hm^3/year during the same time period (Figure 1). As a result, pollution is a greater concern at national level for tomato production compared with water consumption.

The average green (20 hm^3) and blue (260 hm^3) WFs for the time period 1997–2008 represent 0.12% and 2.3%, respectively, of their water colour components for the national crop production as presented on Chapter 6. The mean grey WF (550 hm^3) during the same time period represents 6.6% of the national grey WF of crop production calculated by Mekonnen & Hoekstra (2011b).

There are sharp differences in the WF in relative terms (m^3/t) [t = tonne = 10^3 kg] for tomato production (Figure 2). Rainfed production has by far the highest WF (970 m^3/t); however the WF in absolute terms (hm^3) is negligible for rainfed production of tomatoes in Spain. The grey WF of open air irrigated and greenhouse production systems are smaller, partly because their yields are much higher.

Figure 3 summarizes the average green, blue and grey tomato WF per unit of product by province, grouping them according to their production importance over the period of investigation. The large differences encountered are related to the different production system (open-air rainfed or irrigated *vs*. covered), crop yields and climate parameters prevailing in each province. The largest producing provinces show a significantly smaller WF (m^3/t).

Differences among growing systems are significant, according to the proportion of water consumed or polluted in the main producing provinces (Table 1). The primary

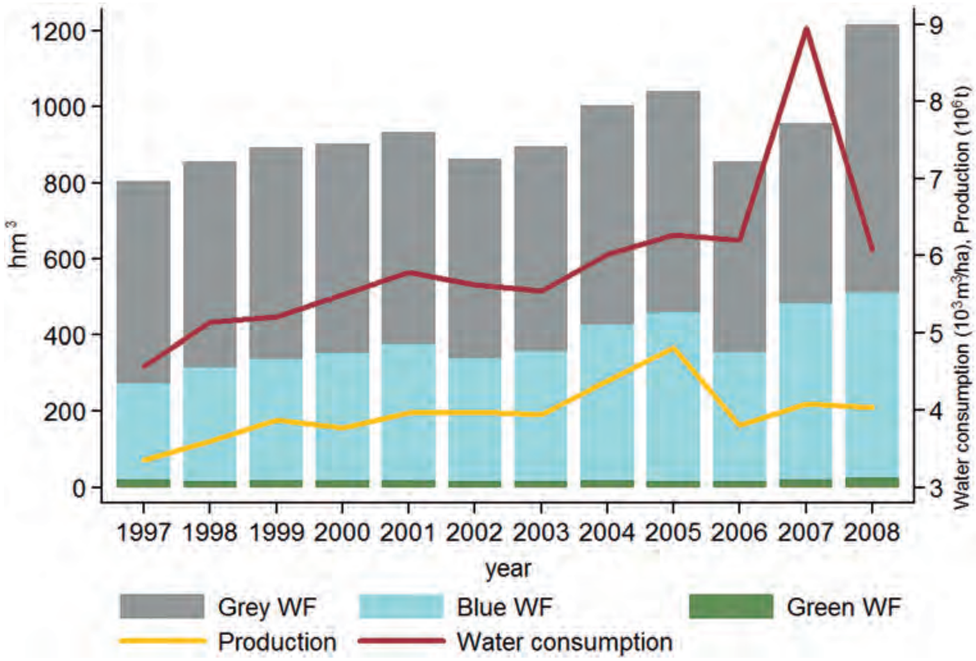

Figure 1 National green, blue and grey water footprint (WF) (hm^3, left axis), national production (Mt, right axis) and water consumption (10^3 m^3/ha, right axis) for tomatoes. (Source: Chico *et al.* (2010)).

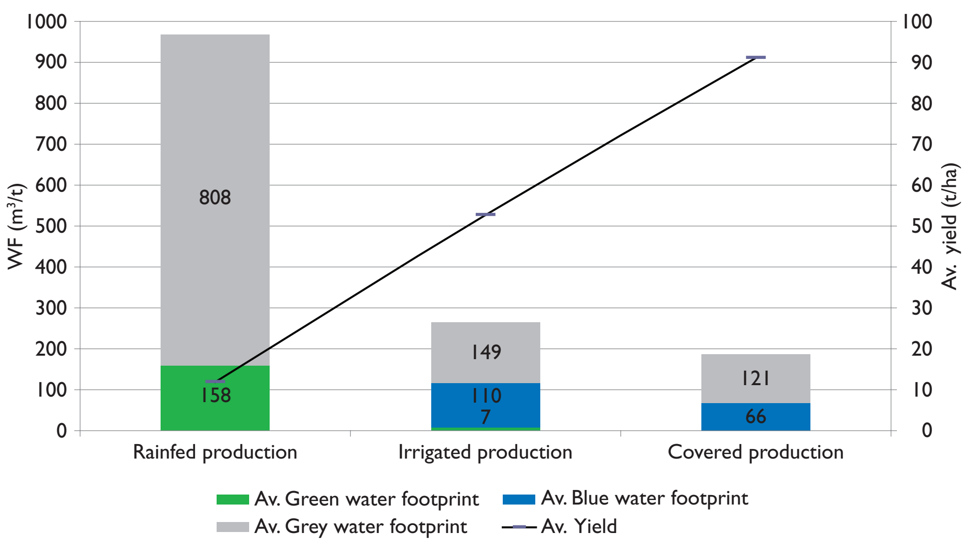

Figure 2 Mean green, blue and grey water footprint per unit of product (WF in m^3/t) of open air (rainfed and irrigated) and greenhouse tomato production and associated average yields (t/ha). (Source: Chico *et al.* (2010)).

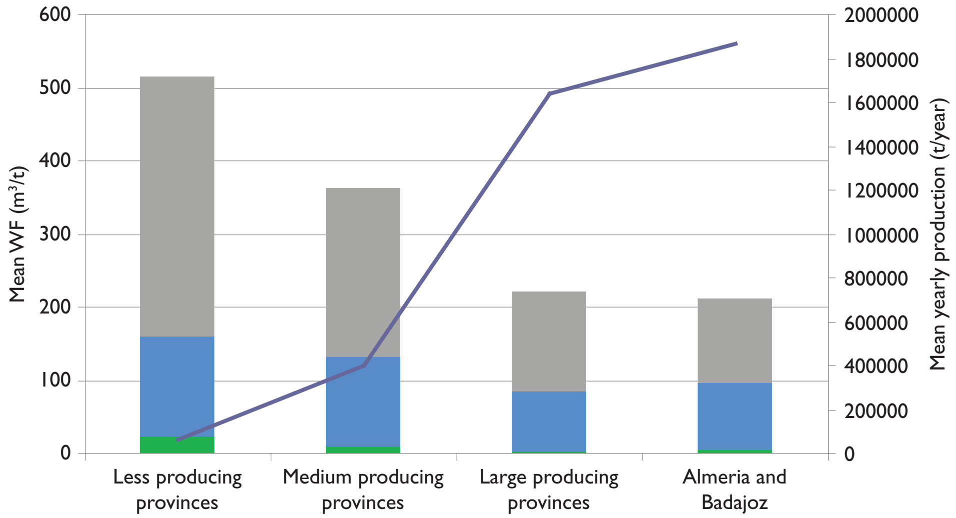

Figure 3 Mean green, blue and grey water footprint per unit of product (WF in m³/t, left axis) in the different Spanish provinces and their mean annual production (t/year, right axis). (Source: Chico *et al.* (2010)).

Table 1 Blue, green and grey share (%) of the total tomato WF (hm³) across the main producing provinces (percentages sum up by row).

	Rainfed		*Open air*			*Greenhouse*		*Total WF*
Province	*Green (%)*	*Grey (%)*	*Green (%)*	*Blue (%)*	*Grey (%)*	*Blue (%)*	*Grey (%)*	*(hm³)*
Badajoz			3	51	46			215
Almería			0.3	4	12	30	54	183
Murcia			1	11	26	20	42	80
Las Palmas	0.1	0.5	0	6	10	35	48	26
Granada			1	9	39	15	37	42
Caceres			2	51	47			45
Seville	0.2	1	2	64	32	0.1	1	25
Navarra			3	28	68	0.5	1	44

Source: Chico *et al.* (2010).

impact of the tomato production in Badajoz (also in Caceres or Seville), is the high volume of blue water consumed, whereas in Almería (but also Murcia, Navarra or Granada) the main impact resulting from tomato production is the grey water generated. The later indicates the volume of freshwater required for assimilating the nitrogen discharge into water bodies.

3.1.1 *The water apparent productivity of tomatoes*

The WAP is an indicator of the economic performance of water use. Over the study period, the WAP of tomatoes varied from 0.025 to 46 €/m³ taking into account all

(50) provinces of study, period and system of production. As shown in Table 2 and Table 3, the WAP depends on the production system, type of water (green or blue) and season of the year. On average, the WAP of tomatoes was 4.30 €/m³ during the period 1997–2008. Greenhouse production has much higher water productivity compared to irrigated open air (Table 2). In tomato production, the prices vary significantly depending on the time of the year, being a strong stimulus for off-season production (autumn and winter) (Table 3). Most of this off-season production takes place in greenhouses.

Tomato production in Almería was worth 641 M€ in 2007, approx. 35% of the total value generated by agriculture in the province (1,800 M€), and 4.9% of the regional Gross Domestic Product (GDP). In Badajoz, on the contrary, tomato production was valued at 649 M€ in 2007, approx. 62% of the value produced by agriculture in this region (1,048 M€), and 6% of the regional GDP.

Table 2 Average yearly production (t), share of greenhouse production (%) and average water apparent productivity (WAP in €/m³) over the period 1997–2008 in the main producing provinces and under different production systems.

Province	*Average yearly production (t)*	*% of greenhouse production*	*WAP of rainfed systems (€/m³)*	*WAP of open air irrigation systems (€/m³)*	*WAP of greenhouses (€/m³)*
Badajoz	1,067,555	0.4		3.1	0.03
Almería	801,324	92		3.9	7.1
Murcia	335,012	76	3.8	3.9	8.8
Las Palmas	179,242	92	18.1	4.6	9.3
Granada	163,314	56		7.3	7.2
Caceres	160,934	0.1		2.2	
Navarra	141,998	2.7		3.4	6.3
National average	**3,968,767**	**3.6**	**2.1**	**3.1**	**7.8**

Source: Chico *et al.* (2010).

Table 3 Percentage of green and blue WF in comparison to the total WF and average water apparent productivity (WAP in €/m³) over the period 1997–2008 for greenhouse production and main producing provinces in relation to the year season. Percentages sum up by row and year season.

	Early season			*Middle season*			*Late season*		
Province	*Green (%)*	*Blue (%)*	*WAP (€/m³)*	*Green (%)*	*Blue (%)*	*WAP (€/m³)*	*Green (%)*	*Blue (%)*	*WAP (€/m³)*
Badajoz	3	97	5.70	5	95	3.80	2	98	10.40
Almería	6	94	9.30	22	78	2.10	3	97	7.90
Murcia	28	72	9.20	24	76	3.40	24	76	10.40
Las Palmas	5	95	11.80	5	95	3.80	3	97	11.10
Granada				5	95	2.20			
Caceres	1	99	22.70	39	61	3.00	1	99	24.00
Navarra	20	80	7.50	24	76	2.70	15	85	9.50
National average	**3**	**97**	**5.70**	**5**	**95**	**3.80**	**2**	**98**	**10.40**

Source: Chico *et al.* (2010).

It is also noteworthy that the source of water is linked to the production system. Provinces using surface water (Badajoz, Cáceres and Navarra) produce around 98% of their production in open-air systems, while the three provinces using almost exclusively groundwater (Almería, Las Palmas and Tenerife) produce over 90% of their tomatoes in greenhouses. The average groundwater apparent productivity is notably higher in production systems that use groundwater (3.70–10.50 €/m^3) compared to those using surface water (3–6.40 €/m^3). This distinction of water productivity based on the origin of water is analyzed in more depth in Chapter 7.

3.1.2 The virtual water exports of Spanish tomatoes

A large proportion of Spanish-produced tomatoes are intended for export, especially those grown in the south-eastern Mediterranean provinces (Almería, Murcia and Granada). On average the annual amount of virtual water exported through tomatoes is 4, 88 and 134 hm^3 of green, blue and grey water, respectively. 93% of these virtual water exports go to the European Union, mainly the UK, Germany and the Netherlands. These exports represent around 0.03% and 1.7%, respectively, of the national green and blue virtual water exports presented on Chapter 6 of this book, and 10% of the grey virtual water exports of Spanish crop products according to Mekonnen & Hoekstra (2011b). However, in economic terms tomatoes exports are more than 6 times larger (9.08 €/m^3) than the national average exports of 1.34 €/m^3.

3.2 The water footprint of olive fruit and olive oil

Over the period 1997–2008 Spanish olive fruit production consumed 5,340–9,720 hm^3/year under rainfed conditions, 630–2,550 hm^3/year of green water in irrigated systems, 460–890 hm^3/year of blue water. Grey water ranges were 950–1,210 hm^3/year (Figure 4). Variation of green water from year to year depends mainly on rainfall. Rainfed olives account for the largest green WF since they occupy from 3.5 (year 2008) to 7.4 (year 1997) times the irrigated area. The lowest annual rainfall in 2005 (with 430 mm) clearly reflected the decrease of the green WF both under rainfed and irrigated conditions. In comparison to the national WF crop production, olive fruit production accounts for 20% and 5% of the green and blue water respectively, and 13% of the Spanish grey water footprint for crop production (Mekonnen & Hoekstra 2011b).

Between 1997 and 2008 the olive orchard area increased from 2.2 to 2.4 Mha, although this increase was mainly due to the expansion of irrigated olive orchards in Andalusia, particularly in the Guadalquivir basin. Olive orchards grew in Andalusia from 230,200 to 507,400 ha. In fact, Andalusia consumed almost 90% of the national blue WF of olive fruit production (760 hm^3) in the year 2008. The expansion of irrigated olives occurred mainly from groundwater sources in the Guadalquivir basin (see Chapter 8), which includes Jaén, Córdoba, Seville and a portion of Granada province (Figure 5). In the last decade the large increase in olive oil production has produced what could be called an *olive oil bubble*. After 2008 olive oil prices dropped, as they tend to approach the market fat world prices. The result is that the hardest hit will be those on rainfed olive groves and irrigated land with high intakes of energy (in some cases the water is raised up to 600 m). In addition, problems related to diversity losses

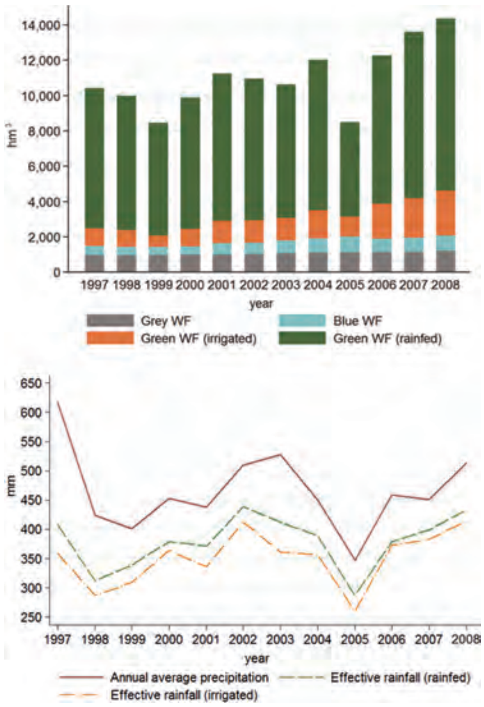

Figure 4 National green, blue and grey water footprint of olive production in hm³ (left) and annual average rainfall and effective rainfall in mm (right) for the period 1997–2008. (Source: Salmoral *et al.* (2011)). This figure has been extracted from the Span. J. Agric. Res. 9 (4): 1089–1104 (2011) with kind permission of INIA (National Institute of Agricultural Research).

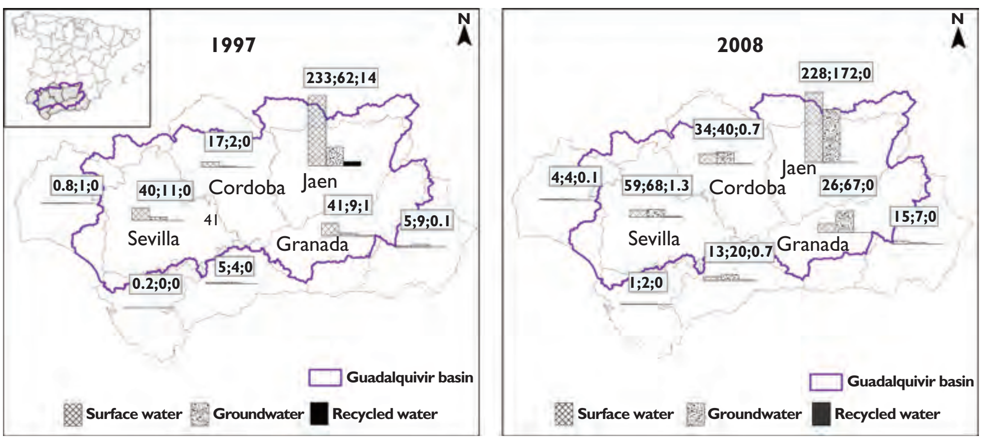

Figure 5 Sources of the blue water footprint (hm³) for olive production along provinces within Guadalquivir basin in 1997 (left) and 2008 (right). (Source: Salmoral *et al.* (2011)). This figure has been extracted from the Span. J. Agric. Res. 9 (4): 1089–1104 (2011) with kind permission of INIA.

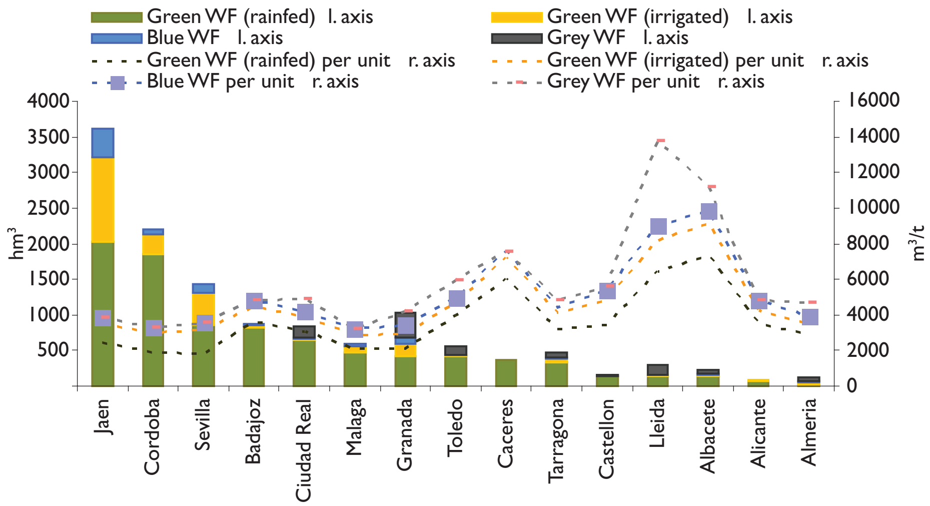

Figure 6 Total water footprint (green rainfed + green irrigated + blue + grey, in hm³) for olive production and the water footprint per unit of product (m³/t) in 2008. Only provinces that comprise ≥1% of the national olive production in 2008 are illustrated. (Source: Salmoral *et al.* (2011)). This figure has been extracted from the Span. J. Agric. Res. 9 (4): 1089–1104 (2011) with kind permission of INIA.

and environmental pressures arise with more intensive olive orchards (Scheidel & Krausmann, 2011).

In 2008 Jaén, Córdoba and Seville jointly accounted for nearly 70% of the national olive production and for 54% (7,260 hm³) of the national WF of olive fruit production (Figure 6). While their total WFs in hm³ are the largest, they are very efficient in terms of WF per unit (m³/t). The provinces showing the highest nitrogen pollution per tonne of crop produced are minor olive producers such as Lleida and Albacete.

The WF of the bottle, cap and label for one litre of bottled olive oil does not represent more than 0.5% of the total supply chain for each year and province of study. In conclusion, most of the water used to produce olive oil can be directly associated with olive fruit production in the field. Spain has the following annual ranges of the WF per litre of olive oil produced: 6,300–11,760 L/L green WF (rainfed); 2,770–4,640 L/L green WF (irrigated); 1,430–2,780 L/L blue WF (irrigated) and 710–1,510 L/L grey WF (rainfed and irrigated). These ranges indicate that providing an unique value of water consumed/polluted by litre of olive oil means giving an average of a broad interval because of changing climate conditions, soil characteristics, water irrigation applied and crop yield across provinces and time.

3.2.1 The apparent water productivity of olive oil

The WAP of olive oil varies in a similar way over the period of study in rainfed and irrigated systems comparing two typical olive oil producing provinces (Jaén and Toledo) located in different regions of Spain (Figure 7), due to the variation of olive oil market prices. In rainfed systems the WAP in Jaén ranges from 0.20 to 0.62 €/m³ and from 0.07 to 0.36 €/m³ in Toledo. The WAP of irrigated systems has shown a

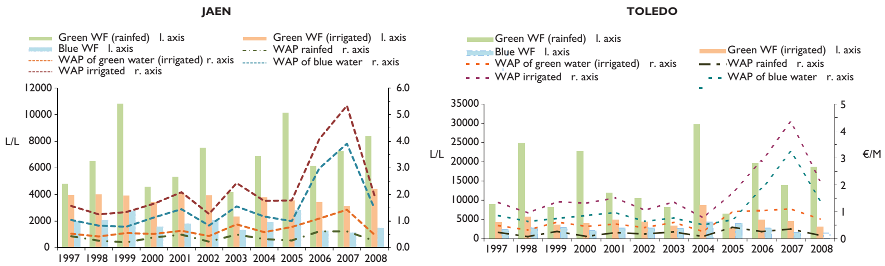

Figure 7 Olive oil water footprint (L/L) and water apparent productivities (€/m³) for both rainfed and irrigated production systems in Jaén (left) and Toledo (right) over the period 1997–2008. (Source: Salmoral *et al.* (2011)). This figure has been extracted from the Span. J. Agric. Res. 9 (4): 1089–1104 (2011) with kind permission of INIA.

relatively stable trend between 1997 and 2005 with values below 2.40 and 1.70 €/m³ in Jaén and Toledo, respectively. The peaks of WAPs in 2006 and 2007 are related to highest olive oil market prices that took place during both years.

3.2.2 *Virtual water exports of olive oil*

The mean annual amount of exported olive oil over the studied period consisted of 4,350; 1,180 and 570 hm³ of green, blue and grey water, respectively. Differences between years are very significant, with green water being the most unstable component and closely dependent on annual precipitation, whereas blue virtual water exports are much more stable. These values show that approximately 70% of the total virtual water exports are green water, which denotes the importance of the green component in the virtual water trade, as reported in previous studies (Aldaya *et al.*, 2010). 23% of olive oil exports correspond to irrigation water, which suggests that expanding groundwater irrigated olive orchards and olive oil exportation may add further pressure to the already stressed Guadalquivir basin. Compared to the national exports of crop products estimated by Mekonnen & Hoekstra (2011b), our results show that olive oil accounts for 32%, 15% and 43% of the green, blue and grey water of the Spanish crop exports. Rainfed olives therefore have an important role in virtual water exports, even if both the area of irrigated olive trees and the related blue water component have increased during the period of study. The volume of grey water exported as olive oil in relation to the total Spanish exports of crop products is relevant, although the largest producing provinces do not generate significant volumes of grey water.

4 CONCLUSIONS

Our study provides an overview of the three water types (green, blue and grey) ascribed to the production of tomatoes and oil olive in Spain, differentiating the various production systems found across provinces and the resulting variation for the water consumed/polluted in absolute terms (hm³) and per unit of product (m³/t). Tomato production shows relatively high blue water use efficiency, although it also shows a high grey WF, implying a pressure over water resources related to nitrogen pollution. WF evaluations that omit the grey component would lead to incomplete conclusions, as they may contribute to increased efficiency in water consumption but fail to consider the environmental quality aspects. In contrast to tomatoes, the total olive oil WF stands out because of the large portion of green component for both rainfed and irrigation conditions. This circumstance makes olive oil production largely dependent on the precipitation pattern.

To obtain a more comprehensive picture, not only water consumed or polluted was considered, but also the associated economic value (WAP in €/m^3). We note important differences in the WAP between provinces, production systems and also throughout the year. The greenhouse tomato system shows the greatest WAP, which may be related to the much higher price of off-season productions and larger crop yield. In addition, groundwater production showed higher blue water productivity than that of open-air irrigated. While the provinces irrigating with surface water mainly produce tomatoes intended for the industry in open-air systems, those using groundwater produce foremost fresh tomatoes for export, which are more valuable. In the case of olive oil, water productivity also varies among provinces over the period depending on production system, climatic-soil conditions and market price variation.

The pattern in both products is that the largest producing places show high water use efficiency per product and WAP, but imply great pressure on the available water resources. The production of fresh vegetables in the southeast of Spain (Almería) shows signs of aquifer depletion. Reductions in leaching would lessen the grey WF per unit of product. Still, overuse would have to be dealt with. In the case of Badajoz province, if production continues increasing, rises in water use efficiency and leaching reductions may be needed. There doesn't seem to be a risk of over-use since significant quantities are available thanks to the presence of large reservoirs, but the impact on the water quality may need to be tackled.

Between 1997 and 2008 olive orchard area more than doubled in the major production centre (Andalusia). Olive oil production has increased and has led to what could be called an *olive oil bubble*. The drop of olive oil prices after 2008 has hit hardest the rainfed olive orchards and those irrigated with high energy costs. This growth took place due to increasing groundwater abstractions in the Upper Guadalquivir basin and has caused concerns about the sustainability of olive irrigation in those areas. This situation led to a water-stressed basin because of over-allocation of available water resources. 23% of olive oil exports rely on irrigation water, which suggests that expanding groundwater-irrigated olive orchards and olive oil exportation may add further demand to the already stressed Guadalquivir basin. However, recently the situation seems to be under control given the deficit irrigation practices with very limited amounts and the constraints imposed by the sharp increase in energy prices.

Another important conclusion of the study is the ranges given for tomatoes and olives WF per unit of product. They show the strong assumptions taken when providing a unique value of the WF because of the widely different climatic conditions, production systems, productivity levels and irrigation schedules across the country. As every water footprint calculation is an estimation, values given are the average of a broad interval.

Irrigation farmers' decisions depend on several factors, particularly for woody crops that have traditionally been grown under rainfed conditions (i.e. olives and vineyards). Firstly, energy costs might not allow farmers to irrigate as much as they wish, particularly in deep groundwater wells (see Chapters 14 and 19). They are also motivated to applied greater amount of irrigation water when market olive oil prices are high, since their cost would be then compensated. The scale of our study did not enable us to take into account farmers' decisions regarding precipitation during irrigation management, by assuming that rainfall is sufficient and reducing their irrigation schedules (García-Vila *et al*., 2008). All these climatic, agronomical and management aspects heavily influence the calculated value of the WF, and should be carefully taken into account for an accurate evaluation of the water use performance of crops.

The results of this study also confirm the importance of a detailed WF assessment of ingredients in the case of agriculture-based products since olives comprise more than 99.5% of the WF of one litre of bottled olive oil, emphasizing the olive fruit production in the field as key to improving water management. Recently, the water label has become a new way of certificating the efficient use of water resources for all water users (EC, 2011). Our results lead us to conclude that the water label would not be accurate for food products if only a single value is given regarding to water consumed/polluted.

Further local crop production studies, completed with a wider range of social, economic and environmental indicators are required for an appropriate sustainability assessment and informed decision making.

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