A Preliminary Assessment of Water Footprint Components in a Mediterranean Olive Grove

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Abstract

The water footprint is an indicator of the consumers' (or producers') water consumption. It can be a useful tool to plan appropriate water management strategies within a territory.

This 4-year (2005-2008) study provides an assessment of the water footprint of an irrigated (I) olive orchard against a rainfed (non-irrigated, NI) one. Olive trees were grown under semi-arid conditions. The irrigated field received treated urban wastewater and was managed according to sustainable techniques (i.e. cover crops, recycle of pruning material). In the NI grove, soil was tilled and pruning residues were removed.

In each year, the water footprint (m^3 t^{-1}) was calculated as the amount of the annual water consumption (m^3) per unit of yield (t). Classical components green, blue, grey (WF_{Blue}, WF_{Green} and WF_{Gray}, respectively) of the water footprint were determined and the total (WF_{Tot}) was calculated as their summation.

On average, total water footprint of the NI block was ~ 45% of that of I block. The WF_{Green} was the most important component in both irrigated and non-irrigated grove, accounting for the 48 and 90% of the WF_{Tot}, respectively.

INTRODUCTION

Water is a resource long wasted, growing expensive, and soon is going to be a really rare good. Aquifers are falling, glaciers vanishing, reservoirs drying up day by day and rivers no longer owing to the sea. Climate change makes these problems worse. As the world population is increasing, the demand for water increases. World population was 2.5 billion in '50s and would reach ~9 billion in 2050 year (United Nations, 2009). Hence, annual water demands for horticultural crop production are expected to increase from approximately 7 million cubic meters to approximately 14 million cubic meters in 2055 (Rosegrant et al., 2007).

The proportion of people living in countries chronically short of water, which stood at 8% at the turn of 21st century, is set to rise at 45% (4 billion) in 2050 (http://www.economist.com/node/16136302). People in temperate climates, where the rain falls moderately all the year long, may not realize how much water is needed for farming. In Britain, for example, farming takes only 3% of all water withdrawals. In the United States, by contrast, 41% is used by agriculture, almost all of it for irrigation. In China, farming takes almost 70%, and in India nearly 90% of the available water. For the world as a whole, agriculture accounts for almost 70% (http://www.economist.com/node/16136302).

To prevent all these bleak forecasts a lot of governments, organizations and researchers are trying to find out ways to reduce the water consumption at a world, national, regional and local level without a significant impact on the production. The water footprint is part of a larger family of footprint concepts that has been developed in the environmental sciences over the past decades. The concept of water footprint has been introduced in 2002 by Hoekstra and Hung (2002) in analogy to the carbon and ecological footprint. It is a consumptive-based indicator of fresh water use of a consumer or

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producer, which takes into account volumes of water used as well as locations of that use. It also considers the direct and indirect water required to produce a product, measured over the full supply chain. Furthermore, the water footprint can give us useful information about water use efficiency and the environmental impact of different cultures. Finally, water footprint can be an indicator of the water quality.

Water footprint is divided in three main components: blue, green and grey. Green water refers to the consumption of rainwater stored in the soil, such as soil moisture and water available for evapotranspiration (Hoekstra et al., 2009). Therefore, the green water footprint of a product can be defined as the volume of rainwater that evaporated from soil and transpired by leaves during the production process. This is normally highly relevant for agricultural products, where it refers to the total rainwater evapotranspiration from the field during crop growth (Hoekstra, 2008). Blue water refers to surface- or groundwater, being the volume of water in ground- (aquifer) and surface water (lakes, rivers, reservoirs) bodies available for abstraction. Consumption of blue water refers to loss of water from the available ground- or surface water body in a catchment area, which happens when water evaporates and returns to another catchment area or the sea or is incorporated in a product (Hoekstra et al., 2009). In the case of crop production, the blue water content of the crop is defined as the sum of the evapotranspiration of irrigation water and the evaporation of water from irrigation canals and man-made reservoirs. In industrial production or domestic water supply, the blue water content of the product or the service is equal to the part of the water withdrawn from ground- or surface water that evaporates and thus does not return to the system where it came from (Hoekstra et al., 2009). The distinction between blue and green water is important, as green water is only available for use by plants at the precise location where it occurs, whereas blue water is available generally for use in a wide range of human-managed systems, including but not limited to use by plants (Milà i Canals et al., 2009). Grey water describes the quality of water for use further downstream (or down gradient in the aquifer) as a result of polluted return flows. A common misunderstanding is that grey water is the amount of polluted water produced from activities within the system. In fact, grey water is defined as the volume of additional freshwater required to assimilate or dilute the load of pollutants based on existing ambient water quality standards rather than the amount of polluted water generated (Hoekstra et al., 2009).

There are really few previous studies regarding the water footprint in orchards. The green water footprint is really important for the Spanish olive oil production, as it represents about 71% in rainfed systems and 12% in irrigated (Salmoral et al., 2010). In New Zealand, the freshwater consumption of the green kiwifruit supply chain and its impact on the environment are increasing (Hume and Coelho, 2011). A similar situation was found for national level distribution and consumption waste of the food chain of Australian fresh mango (Ridoutt et al., 2009).

The present study analyzed the water footprint and its three main components (blue, green and grey water footprint) in an olive orchard located in a semi-arid area of southern Italy over the period 2005-2008. The aim of this study was to further the understanding of water impact during the production in an olive grove under different management systems, namely irrigated and rainfed, by giving a detailed report of the three components.

MATERIALS AND METHODS

The experiment was performed in a mature olive orchard located in southern Italy (*Olea europaea* L. 'Maiatica di Ferrandina', 8 x 8 m planting distances). During the experimental trial (2005-2008), two blocks (approx. 1 ha each) were identified in the field and differently managed.

Irrigated (I) block: trees received treated urban wastewater (drip irrigation), at a 1-2-days rate calculated according to the FAO methodology (Allen et al., 1998). The soil was not tilled; spontaneous cover crops were mowed 2-3 times per year, and prunings were recycled in loco. This block received approx. 110-135 kg ha^{-1} nitrogen (through fertigation + irrigation water).

Non-Irrigated (NI) block: soil was tilled (10 cm depth, × 3-4 times a year), pruning residues were removed from the field. Approx. 60 kg ha^{-1} of nitrogen were supplied (fertilization) each year.

Rainfall data and reference evapotranspiration (ET_0) were provided by a standard weather station (SAL-Service, Regione Basilicata) located nearby the experimental orchard. Crop evapotranspiration was then calculated according to Allen et al. (1998). Yield and irrigation volumes (I block) were recorded in the different experimental years. The total water footprint (WF_{Tot}), expressed as m^3 t^{-1}, was evaluated from spring (April) till harvest (October) taking into account its green (WF_{Green}), blue (WF_{Blue}) and grey (WF_{Grey}) components (equation 1) (Hoekstra et al., 2009; Salmoral et al., 2010).

$$WF_{Tot} = WF_{Green}+WF_{Blue}+WF_{Grey} \quad (1)$$

The WF_{Green} (m^3 t^{-1}) refers to the consumption of green water resources per unit yield, and it is equal to green water evapotranspiration (ET_{Green})/yield under the assumption that soil available water was totally consumed by the crop systems during the reference period, and that crop evapotranspiration during autumn-winter period was negligible.

The WF_{Blue} (m^3 t^{-1}) refers to the consumption of blue water resources (surface and ground water) per unit yield, and it is equal to:

WF_{Blue} = blue water evapotranspiration (ET_{Blue}) or the annual irrigation volumes per unit yield (equal to 0 in the case of the Non Irrigated olive orchard).

The WF_{Grey} (m^3 t^{-1}) refers to pollution and is defined as the volume of freshwater that is required to assimilate the load of pollutants based on existing ambient water quality standards. It was calculated by the formula of Hoekstra et al. (2009):

$$WF_{Grey} = (\text{N-applications} \times a)/(c_{max} - c_{nat})/\text{yield} \quad (2)$$

where:
N-applications = N applied by fertilizers and irrigation water (kg ha^{-1});
a = nitrate leaching fraction equal to 10% of the N-applications (Chapagain et al., 2006);
c_{max} = maximum acceptable concentration of nitrate as reported in the appropriate guidelines for irrigation water quality standards (equal to 50 mg NO_3 L^{-1}), and
c_{nat} = naturally occurring nitrate concentration of the receiving water bodies, which was assumed negligible.

The sum of the WF_{Green} and WF_{Blue} has been labeled as water footprint (*WF*) according to Hoekstra et al. (2009).

RESULTS AND DISCUSSION

On average, the rainfall measured during April-October interval was ~ 290 mm. The *WF* was affected by both rainfall and irrigation volumes applied that, in turn, influenced crop levels (Tables 1 and 2). Except for the year 2008, WF_{Tot} was higher in I (Fig. 1). Among the water footprint components, WF_{Green} was the most important one in both systems, accounting for the 48 and 90% in I and NI, respectively (mean 2005-2008) (Tables 1 and 2). This finding is noteworthy considering that olive groves are usually managed under rainfed conditions. Therefore, strategies aimed to improve rainwater recharge in soils by using specific soil management techniques such as cover crops, should be applied. Two studies carried out in the same experimental area (Palese et al., 2009; Celano et al., 2011) revealed that the soil of a rainfed cover cropped mature olive orchard intercepted and stored higher amounts of rainwater than tilled, resulting in a significant soil water reserve at the deepest soil layers (> 1.0 m), convenient for the root system of rainfed olive trees in the driest months. In the case of olive trees, a species able to take water at soil water potential (-2.5 MPa) lower than the classical wilting point (-1.5

MPa), a greater soil available water means an effective water availability for good yields (Xiloyannis et al., 1999).

The WF_{Grey} was greater in I because of the highest N supplies by fertilizations and irrigation water (Fig. 2). It represented around 10% of the WF_{Tot} in both systems. Particularly for I, this component was quite low showing an opportune fertilization management.

CONCLUSIONS

Comparative studies at local scale on the assessment of the water footprint should be stimulated in order to define the efficiency of different orchard systems (plant density, pruning operations and plant size, soil management, irrigation schedule, etc.) in managing water sources. Such information combined with surveys on other fundamental aspects (socio-economic, environmental) could give a useful tool to draft guidelines for the best orchard management in accordance with environmental policies.

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Tables

Table 1. Green (WF_{Green}) and blue (WF_{Blue}) water footprint ($m^3\ t^{-1}$) and their sum (WF) for olive production in southern Italy (Irrigated orchard).

Year	ET_{Blue}	ET_{Green} (mm)	ET_{Total}	Yield ($t\ ha^{-1}$)	WF_{Blue}	WF_{Green} ($m^3\ t^{-1}$)	WF
2005	327.8	446	773.8	9.6	342	465	807
2006	347.8	485	832.8	3.6	966	1,347	2,013
2007	399.8	549	948.8	10.4	384	528	912
2008	628.3	447	1,075.3	16.2	388	276	664

Table 2. Green (WF_{Green}) and blue (WF_{Blue}) water footprint ($m^3\ t^{-1}$) and their sum (WF) for olive production in southern Italy (Non Irrigated orchard).

Year	ET_{Blue}	ET_{Green} (mm)	ET_{Total}	Yield ($t\ ha^{-1}$)	WF_{Blue}	WF_{Green} ($m^3\ t^{-1}$)	WF
2005	0	446	446	7.0	0	637	637
2006	0	485	485	0.0	0	0	0
2007	0	549	549	8.0	0	686	686
2008	0	447	447	6.5	0	688	688

Figures

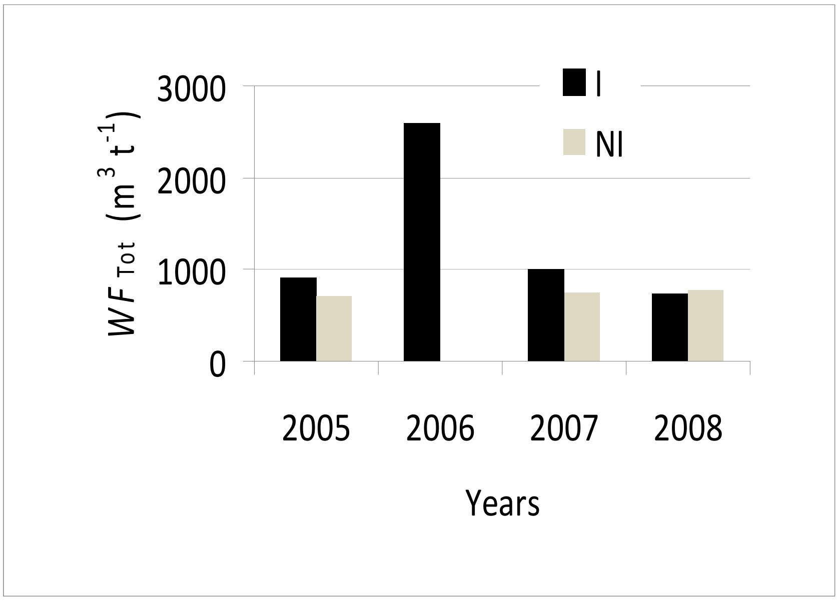

Fig. 1. Total water footprint (WF_{Tot}) (m^3 t^{-1}) calculated for the irrigated (I) and non-irrigated (NI) blocks during the experimental period.

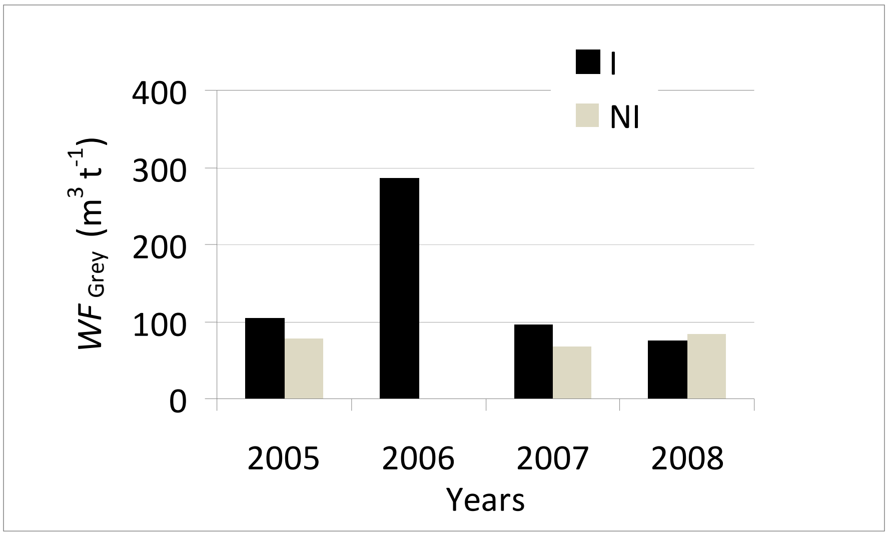

Fig. 2. Grey water footprint (WF_{Grey}) (m^3 t^{-1}) calculated for the irrigated (I) and not-irrigated (NI) blocks during the experimental period.