Journal of Cleaner Production 112 (2016) 2407–2418

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Application of water footprint to olive growing systems in the Apulia region: a comparative assessment

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ARTICLE INFO

Article history:
Received 17 September 2015
Received in revised form
18 October 2015
Accepted 19 October 2015
Available online 27 October 2015

Keywords:
Olive oil sector
Freshwater consumption
Water footprint assessment
Blue water
Irrigation

ABSTRACT

Agriculture is acknowledged worldwide as a great contributor to global emissions of greenhouse gases (GHGs) such as carbon dioxide, methane and nitrous oxide, in particular when there is no efficient management of the resources involved. Agriculture is also the largest freshwater consumer, accounting for almost 70% of the world's water withdrawals. Therefore, it is essential at the local, regional and global level to shift towards sustainable agriculture and food-production systems by using practices that are much less GHG emitting and, both fossil-fuel and water demanding but enable preserving yield, quality and safety of agro-foods. In this regard, Life Cycle Assessment (LCA) and other tools, such as Water, Carbon, Nitrogen and Ecological Footprints, are increasingly playing an important guiding role.

In this context, this research was designed to compare Water Footprint (WF) of different olive agronomic cropping systems, which reduce water demand at the regional and global levels.

Based upon results obtained, the high-density cropping system was found to be the most competitive due to the reduced $WF_{(tot)}$ compared with the other systems investigated. Hence, the authors recommend expanded implementation of agricultural practices designed to reduce the WF, to enhance environmental sustainability and to optimise management and ecological costs in the olive production sector. This research contributes to enhance the knowledge on the applicability and usefulness of foot-printing tools for assessing and enabling more environmentally sustainable agricultural systems for water usage.

1. Introduction

Agricultural and food sectors, though contributing to human and health and prosperity, cause many environmental impacts (Ingrao et al., 2015). In this regard, agricultural policies have played a crucial role, since they have been designed for decades for increasing yields with emphasis upon external inputs, such seeds, pesticides, mineral fertilisers, and agricultural equipment (Bagheri, 2010). Currently, as many farming systems are designed and managed, they are often characterised by high productivity rates, but they negatively affect the global environment in multiple ways: therefore, they are not truly ecologically sustainable. According to Soussana (2014), if not sustainably managed, agricultural activities contribute to land degradation, natural resource exploitation and greenhouse gas (GHG) emissions. In particular, apart from the high GHG-emissions, agricultural production accounts for around 85% of global freshwater consumption, with irrigation accounting for around 70% of all freshwater withdrawals (Ridoutt et al., 2009; Lamastra et al., 2014). In this regard, Rost et al. (2008) reported that global consumption of basin-water associated with agricultural systems generally range between 1200 and 1800 km^3 per year.

In this context, it was underscored that the increasing over consumption of freshwater resources, as a result of the global population growth, is accelerating freshwater scarcity and quality issues worldwide (Lamastra et al., 2014). In this regard, water availability uncertainties and accelerated water pollution are increasingly making the public, private and research sectors acknowledge that water security is a global concern (Lamastra et al., 2014) that must be addressed now. Regional economic competitivity can be endangered due to increasing demands for freshwater and resultant higher risks of supply disruptions if the

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http://dx.doi.org/10.1016/j.jclepro.2015.10.088
0959-6526/

demand approaches or exceeds the annual renewable supply (Daccache et al., 2014). According to Lamastra et al. (2014), this may represent a limiting factor for economic development, especially in water-stressed regions, like the Mediterranean, where agriculture is one of the most productive and vital sectors. In the Mediterranean Region (MR), agriculture employs more than a fifth of the population and contributes >10% Gross Domestic Product (GDP) in eight of the component countries (Daccache et al., 2014). Thanks to its characteristics of mild winters and hot dry summers, this region is particularly suited for production of a diverse range of crops such as olives, citrus, grapes and cereals, as well as high-value horticulture (Daccache et al., 2014). As precipitation across the region undergoes high inter-annual and seasonal variability (Correia et al., 2009), irrigation is an essential component of production for many farmers to support crop diversification, to help to ensure good, high quality yields and to help to ensure security of food supplies (Hanjra and Qureshi, 2010). In the MR, the irrigated area has doubled over the last forty years and now represents almost 20% of the total cultivated agricultural land, while the water basins have been drawn down rapidly due to the extensive irrigation demands (Daccache et al., 2014). In particular, the water demand for cultivation is concentrated in river basins and aquifers where the level of stress is already classified as 'extremely high' (>80% available water used). A further 17% of the demand is located in catchments designated as having a 'high' level of stress (80–40% of available water used). Only the remaining portion is located in regions where fresh water supplies are considered as sustainable and sufficient to meet current and near-term projected needs for households, industry and agriculture (Daccache et al., 2014). In Italy, based upon FAO-Aquastat (2012), total freshwater withdrawals were estimated as equal to 45.08 km^3 in 2007 (the latest available data), of which 28.59% (12.89 km^3) was used in agriculture. In this regard, Daccache et al. (2014) showed that the highest irrigation demands are concentrated in the Po Valley, in Apulia, in the majority of Sicily and in most of the coastal areas of the nation, mainly due to their high agricultural and touristic applications. Unfortunately, as shown in Fig. 1, those areas, as most of the MR, grow under high and extremely-high water stress conditions, thus emphasising upon the need to find ways for limited exploitation of 'renewable' water resources.

Therefore, it is essential and urgent at all levels (local, regional and global) to shift to more sustainable food-production systems that reduce water utilisation compared to those currently under development (van der Werf et al., 2014). According to this author team, this can be achieved through the adoption of practices oriented to water preservation and the treatment of wastewaters in ways that make them compatible for reuse as irrigation and dilution waters in agriculture. In doing so, care should be taken to preserve soil quality and also the yield, quality and safety of agro-foods and to ensure that our great-great grandchildren will also have water to use in producing their food and fibre. In this regard, an important guiding role is increasingly being played by Life Cycle Assessment (LCA) and other tools such as, for instance, Carbon Footprint (CF) and Water Footprint (WF) (van der Werf et al., 2014). These tools are useful for quantifying the GHG emissions, water consumption and global environmental impacts of agricultural products in their life cycles (Notarnicola et al., 2012). Based upon this definition, according to Baldo et al. (2008), application of the aforementioned tools enable process revision and streamlining through evaluation of potentials for reduction of: GHG emissions;

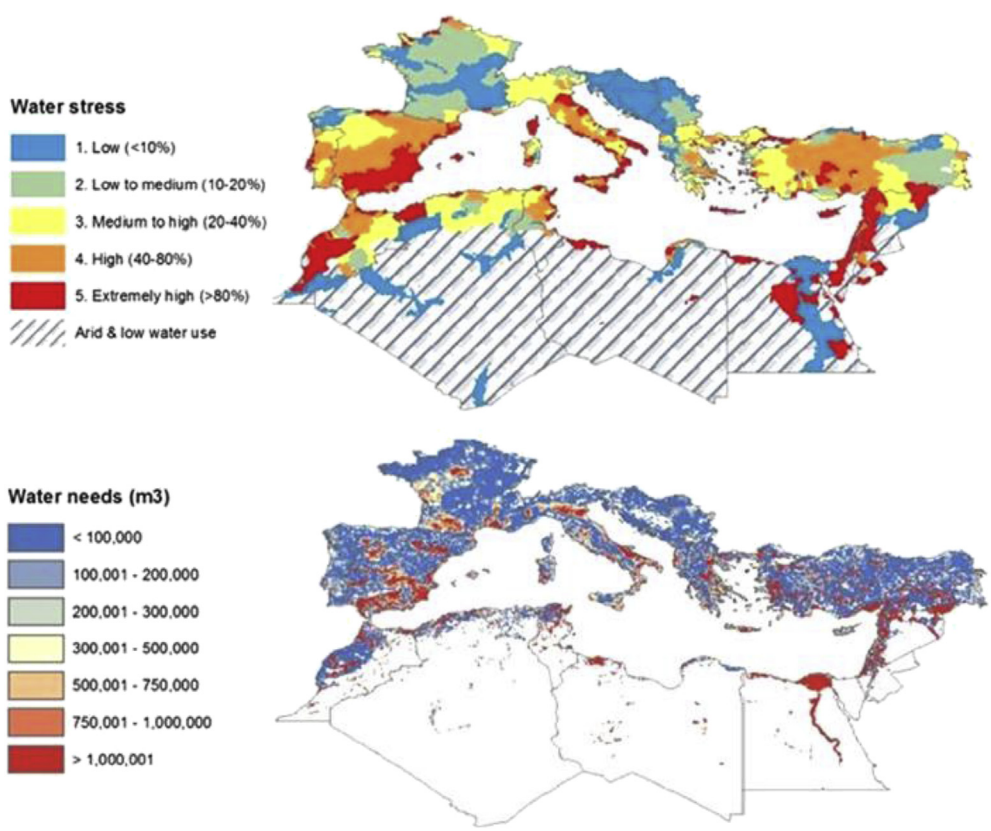

Fig. 1. Water stress and volumetric irrigation water demand (m^3) across the Mediterranean region, based upon the global water stress index produced by Gassert et al. (2013), that provides a spatial assessment of demand for freshwater from households, industry and irrigated agriculture, relative to freshwater availability in a typical year. The figure was extrapolated from Daccache et al. (2014).

consumption of fossil fuels and water; environmental impacts, such as climate changes and the exploitation of natural and non-renewable energy resources.

Those tools can be used to compare different products or processes in order to determine preferable options in terms of reduced global environmental impacts, thereby assisting in decision-making. In this context, this study was designed to compare the WFs of different cropping systems, which represent well the current regional practices in the olive sector. The groves investigated are located in the province of Bari (Italy), which is the most intensive production area of the Apulia region with regard to both area invested and yearly production. The objective of the research was to investigate the need for and ways to accomplish reductions in water usage at local and regional scales. The research was focussed upon olive farming, because it a very important element of the cultural heritage of Apulia and has a crucial role in the economy of the Region. In particular, high-density cropping systems are increasingly being implemented in order to maximise production yields compared to the traditional ones. Therefore, proper environmental evaluations, as the one discussed in this paper, are needed for performing comparative assessments of alternative water management systems. This research is part of broader investigations in the olive sector focussed upon improving global environmental sustainability, which will include research on Carbon, Nitrogen and Ecological Footprint reductions, and LCAs for making holistic improvements.

The following section reviewed the methodological approach used for WF estimation, as the foundation for this research.

2. The theoretical approach to water footprint analysis

The increasing scarcity of freshwater and the important roles that water plays in food production and all other dimensions of human and eco-system health emphasise upon the need to optimise water utilisation in all human activities and, in particular, in agriculture since this sector is acknowledged worldwide to be highly water consuming (Chouchane et al., 2015). The topic of water management requires a multidisciplinary approach, which affects in a sustainable way the whole process of water governance. In particular, a multidisciplinary approach has to overcome the classic engineering approaches adopting indicators that combine the material basis of water utilisation with information regarding the efficiency, carrying capacity and resilience of natural basins (Amicarelli et al., 2011). In this context, WF is an indicator that enables assessment of the state of the art of the sustainability associated with water resources (Amicarelli et al., 2011). It was introduced by Hoekstra (2003) to enable quantification of water consumption and pollution, as needed for the planning of mitigation interventions and, as a result, to foster implementation of more sustainable water usage practices (Lamastra et al., 2014; Schyns and Hoekstra, 2014).

WF can be considered as an aggregate and multidimensional indicator of water usage, because it can be used to help to quantify the different types of water consumption as a function of space and time. In this regard, WF differs from the traditional concept of water balance (Hoekstra et al., 2011), because the latter only describes the flow of water in and out of a system by considering consumptive water usage (Lamastra et al., 2014).

Because of the huge water consumption associated with human activities, water utilisation and management at local, regional and global levels must be focussed upon more sustainable practices. In this context, the importance and the usefulness of WF led to the development of the WF Assessment (WFA) framework developed by Arjen Hoekstra in 2011 (Hoekstra et al., 2011) as a distinct field of research and application (Schyns and Hoekstra, 2014). WFA is a tool for WF quantification, interpretation and reduction to guide the development, testing and implementation of sustainability in all human activities, including agricultural practices. According to Boulay et al. (2013), the Water Footprint Network (WFN), together with its partners and other researchers, established a methodology for development of WFAs based upon global WF standards. The WFA methodology addresses appropriation of freshwater resources in a four-step approach including goals and scope setting, water footprint accounting, sustainability assessment, and response formulation (Hoekstra et al., 2011; Boulay et al., 2013). The accounting phase includes the quantification and mapping of freshwater usage by three distinct types of water: blue, green and grey (Hoekstra et al., 2011; Boulay et al., 2013). The first component refers to global surface and groundwater involved in the production of goods and services that are utilised by individuals, communities or economic activities. Compared to the total amount of available freshwater, this component measures the water consumed in the economy and the water available to sustain the ecosystem. Green water is the volume of rainwater used by crops to grow and is referred to precipitations that do not run off or renew groundwater and that so are stored in the soil. The last component, namely grey water, refers to the volume of water that is polluted during a production process and is referred to the volume of water needed to dilute the pollutants discharged into the natural water system in such a way that the final water quality remains constant with respect to specific quality standards (Hoekstra, 2009; Amicarelli et al., 2011; Chouchane et al., 2015). So, according to Lamastra et al. (2014), there is evidence that, in contrast to water balance, WF includes other types of water such as rainfall (green water) and as polluted by human activities (grey water), and excludes water consumption (blue water) insofar as water is returned to its source. Also, the WFA methodology provides a comprehensive indicator to quantify embedded water volume consumed along the life cycles of products (from direct water extraction to water pollution), therefore, documenting the impacts upon basin-water availability.

Finally, the methodology enables documentation of detailed information about the different impacts of water consumption and can provide guidance for improved water stewardship in the agro-food sector (Herath et al., 2013; Lamastra et al., 2014; Chouchane et al., 2015).

3. A review of water footprint studies in agriculture

Over the years, WFAs have been performed in numerous agricultural sectors. For instance, Huang et al. (2012) assessed the WF associated with the consumption of a number of crops produced in Beijing, namely winter wheat, spring and summer maize, soybean, sweet potato, groundnut, watermelon and various vegetables in both open and covered systems. Also, Shrestha et al. (2013) performed a WFA, according to the global WF standard (Hoekstra et al., 2011), of the production of nine crops (wheat, rice, maize, millet, potatoes, sugarcane, lentils, pulses, mustard seed and vegetables) in Nepal using local meteorological, agronomical and irrigation data at high spatial resolution. Similarly, Chapagain and Hoekstra (2011) quantified fresh water usage for rice production at a global level. For this purpose, the authors distinguished between two different sources, namely irrigation water withdrawn from ground or surface water (blue water) and rainwater (green water), and also calculated the volume of polluted water due to agricultural nitrogen usage.

In research on production of fruits and vegetables, Stoessel et al. (2012) performed LCA-based CF and WF for the environmental assessment of 34 types of fruits and vegetables of a large Swiss retailer. Through the study, the team of authors provided

environmental decision-support to the retailer and developed life cycle inventories (LCIs), which are also applicable to other case studies.

Other research in this area was performed by Brito de Figueirêdo et al. (2014) and Almeida et al. (2014). The first team quantified the average impact upon freshwater availability throughout the life cycle of Brazilian exported yellow melons and documented that irrigation for plantation growth represented almost 98% of the impact. The second team assessed WF of tomato production in a greenhouse in Northern Italy and found that direct water consumption for irrigation was the largest contributor to the tomato production WF.

Morillo et al. (2015) proposed a joint evaluation of crop WF-accounting and irrigation management performance indicators as a diagnostic tool to identify the hotspots of irrigated agricultural systems for production of high-value and water-intensive crops, like strawberries. The authors found those hotspots to be mainly related to water abstractions from aquifers, fertiliser production and consumption, as well as aquifer pollution. Moreover, they found that these impacts could be reduced through implementation of precision irrigation systems.

Numerous WF studies were conducted in the field of wine production. For instance, Herath et al. (2013) assessed the impacts of wine supply chain on the water resources of two different wine-producing regions in New Zealand considering all hydrological inflows and outflows of the system. Based upon the findings of the study, the major impact on water quality and quantity resulted from the grape-growing stage and the greatest contribution was from the grey and green components.

Additionally, Lamastra et al. (2014) assessed the WF of six different wines from the same winery in Sicily (Italy). They developed a methodology based upon a new approach for grey-water calculation, to consider several scenarios in which different management options were compared. In another study, Bonamente et al. (2015) applied this evaluation procedure to red wine produced by an Umbrian winemaking company. For this purpose, the authors chose the common 0.75 L wine bottle as the functional unit and used primary data provided by the producer. Results showed a total WF of 632.2 L/bottle, with the major contribution (98.3%) given by green water, and minor contributions coming from the grey (1.2%) and blue (0.5%) water components. Similarly, Ene et al. (2013) performed WFA, according to Hoekstra et al. (2011), of one 750 mL bottle of wine produced in a medium-size plant in Romania considering a four-year period characterised by different precipitation regimes. The study documented that almost all of the WF was related to the supply-chain and, in particular to the growing phase, out of which 82% green, 3% blue and 15% grey. Furthermore, Quinteiro et al. (2014) assessed the impact coming from the use of freshwater for production of a Portuguese wine by applying some of the methods that are currently available within the LCA framework. At the impact assessment level, the authors found a large variability for the freshwater usage impact, mainly because of the different characterisation factors considered by each of those methods.

Finally, Williams (2014) focussed upon Chardonnay grapevines grafted onto two different rootstocks and performed statistical analyses on eight year's data. They documented that diverse irrigation practices had significantly different impacts on water-use efficiency and on water footprints.

Regarding olive production and processing, Salmoral et al. (2011) evaluated WF of both Spanish olives and olive oil over the period 1997–2008, by taking into consideration the three water components discussed in section 2. Over the studied period, the green WF in Spanish olive oil production represented about 72% in rain-fed systems and 12% in irrigated olive orchards, while the blue and grey components represented 6% and 10% of the national WF.

Additionally, Nogueira et al. (2012) used evapotranspiration measurements to estimate the water footprint of a high-density olive grove in southern Portugal (cv. Arbequina, drip irrigated, 1975 trees ha^{-1}), during 2011. In Italy, Dichio et al. (2014) analysed WF of an olive orchard located in a semi-arid area of southern Italy using four years of data (2005–2008). According to their findings, the WF_{green} was the most important compared to the other components in irrigated and rain-fed systems, accounting for 48% and 90%, respectively. Furthermore, Amicarelli et al. (2011) performed a WFA to quantify the WF value associated with an average yearly production of 670 kt of Italian olive oil during the period 2003–2006. In particular, 71% of the oil amount was produced in Apulia (37%) and Calabria (34%), whilst the remaining amount is almost equally imported from Spain and Greece. In particular, the team of authors evaluated the total WF for the annual production of that olive oil amount as approximately 1700–3700 Mm^3 corresponding to 2500–5500 $m^3\ t^{-1}$ of generated oil. Also, the authors found wide rages for the values related to the three WF components, especially for the green one. This was attributed to the whole supply chain and, in particular, to the agricultural phase as it is developed in vast and cultivation areas under different soil and climate conditions. Those ranges were found to be: 6–40% for WF_{green}; 15–35% for WF_{blue} due to the irrigation and fertilisation operations; and, 45–55% for WF_{grey}, directly linked to the production and usage of fertilisers.

All studies reviewed highlighted the importance of WF as a tool to support companies and farmers in their strategic planning for improved allocation of the water resources utilised during the whole supply chain. In addition, from the findings of these studies it is clear that the highest contribution to WF in agriculture is the blue component, mainly due to the water consumed for irrigation, and both fertiliser production and dilution. However, in the case of grape growing, the greatest contribution to WF was from the green component because, as stated by Ene et al. (2013), grapes are mainly grown with green water, since irrigation is performed only when severe drought periods occur. In this context, studies by Herath et al. (2013) documented that wine production, including the grape cultivation phase, had no deleterious effects on water resource depletion and therefore, can more easily comply with eco-friendly agricultural production policies. Researchers such as Lamastra et al. (2014) and Bonamente et al. (2015), through application of a specific WF calculation method, underscored the importance of WF_{grey} estimation in accounting of water and soil contamination as a consequence of fertilisation activities.

However, it should be observed that results from the studies reviewed were strictly linked to:

- the type of crop grown, which means different Irrigation Requirement (IR) rates;
- the climate and soil conditions of the given cultivation area, that mainly affect Crop Evapotranspiration (ET_c) and rainfalls (P_{eff}) and, in turn, the irrigation volume (I_{eff});
- the farming system adopted (conventional or organic) and the agricultural activities performed, thereby having influence upon the production and administration of mineral rather than organic fertilisers;
- WF calculation methodology.

In addition, the review highlighted deficiencies in the application of WFAs in comparisons of different cropping systems and underscored the need for more research on ways to improve agricultural water management. In this context, the research reported

Fig. 2. Geographical distribution of suitable areas for olive-tree production in the world.
Source: International Olive Council[1]

upon in this paper presented results from comparative WF assessments done to study traditional, intensive and high-density systems, based upon water requirements of olive orchards.

4. Olive production data at the local and regional scale in Italy

The olive tree is a highly distinctive element in the Mediterranean area, since it contributes to formation of the Mediterranean landscape and it is widely distributed in natural systems and agricultural cropping and agro-forestry (Loumou and Giourga, 2003). In this area, olive farming is an important element of the cultural heritage and has a crucial role in the economy with significant social and environmental impacts. Moreover, traditional production systems contribute to landscape conservation and to protection of the environment against erosion and desertification. The areas of the world that are most suitable for olive-tree production are depicted in Fig. 2: olive trees are planted in all regions of the globe mostly between 30 and 45° latitude in the two hemispheres (FAOSTAT, 2015).

According to the International Olive Council (IOC) estimates, over the last decades the olive-growing areas have been rapidly expanding, mainly due to the development of production systems using new mechanisation technologies for harvesting and pruning, based upon intensive growing systems. There has been a significant increase of olive consumption in countries that are not acknowledged as "olive-oil consumers" and, as a result, an intensification of trade and a growing internationalisation of the markets is occurring. Although it accounts for less than 3% of the world edible oil market, olive oil is attracting growing interest from new countries (Barjol, 2014).

As a consequence, based upon global data drawn from the Food and Agricultural Organisation of the United Nations (FAO), it is clear that global olive production as depicted in Fig. 3 increased from an annual production of 10.93 Mt in 1993 to 20.40 Mt in 2013 (FAOSTAT, 2015).

Based upon data in Fig. 4 it is clear that Europe is the largest olive producer with almost 11 Mt produced annually between 1993 and 2013. Other olive producers are from Asia (2.43 Mt y^{-1}) and Africa (2.39 Mt y^{-1}) (FAOSTAT, 2015); others are located in the "emergent" countries (Chile, Australia, Argentina, US etc.) that are increasingly gaining new important roles in global markets.

In the European context, as presented in Fig. 2, the Mediterranean countries clearly dominate world olive production, consumption and trade with the three leading producers being Spain, Italy and Greece (Fig. 5). In particular, a production of an average of 3.22 Mt y^{-1} (in the period 1993–2013) was recorded in Italy, therefore being the second largest producer worldwide after Spain, with an annual production of 5.21 Mt (average 1993–2013) (FAOSTAT, 2015).

In the EU context, olive farming is very heterogeneous since there are several differences not only in terms of olive farming area, ranging from the very small (<0.5 ha) to the very large (>500 ha), but also in terms of organisation of the farm (traditional, intensive, and high density plantations).

Particularly, the Italian olive sector is characterised by an extreme fragmentation of companies and by the prevalence of traditional plantings (mostly hand harvested). This fragmentation was caused by the different cultivation techniques, the varietal heritage (about 500 varieties of native olives), secular adaptation of cultivation techniques to the environmental and climatic conditions, and the economic and social structure. This perennial Mediterranean cultivation is notable in marginal regions (mountainous or hilly areas), with low productivity rates because it is compatible with other agricultural and non-agricultural activities. Additionally, it has an important environmental capacity that enables diversification of production according to: biological succession of the olive trees; farming methods (with or without irrigation); varieties planted and varied soil and climatic conditions. The Italian olive oil sector is based upon a variety of small non-industrial oil mills that are characterised by different degrees of integration in the supply chain and also by deep cultural roots in the territory (Pomarici and Vecchio, 2013).

The Italian olive oil sector is characterised by a high quality production of extra virgin olive oil: indeed, 43 of the producers are certified by the PDO (Protected Designation of Origin), five of which are from Apulia according to data recently updated (May 22, 2015) by the Italian Ministry of Agriculture, Food and Forestry (MIPAAF, 2015).

Apulia is the first and most important olive-producing region in Italy, according to the Italian Institute of Statistics (ISTAT, 2015). In particular, in 2011 (the latest available updated data from ISTAT) the agricultural surface invested in Apulia for olive production was equal to 0.374 Mha, thus representing 32.25% of the corresponding national one (1.16 Mha). In the same year, olive-production levelled out at 1.21 Mt, thereby representing 35.07% of the amount

[1] The International Olive Council is the world's only international intergovernmental organisation in the field of olive oil and table olives. Members account for 98% of world olive production that are located primarily in the Mediterranean region.

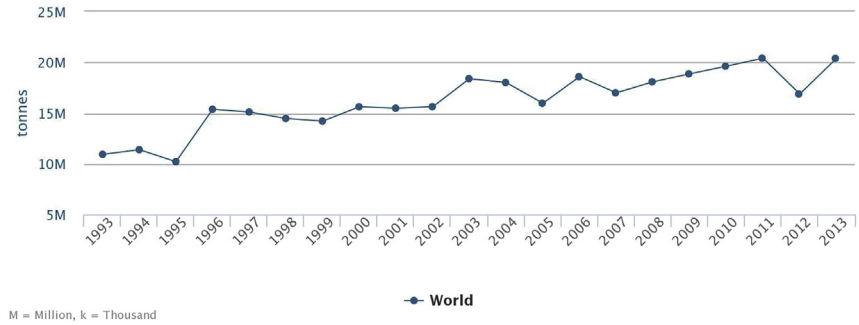

Fig. 3. Olive production trends at the world level.

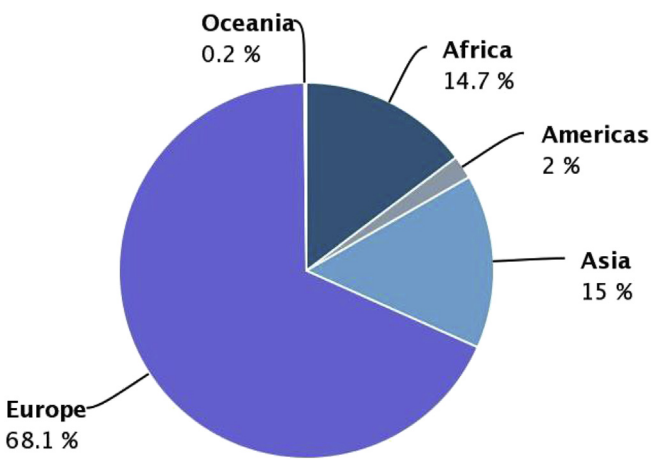

Fig. 4. Annual production of olives at the global level (average 1993–2013).

produced at the national level (3.45 Mt). On average, 90% of olive production (1.21 Mt) is used for oil production and the remaining 10% is used for production of table olives and derivatives (ISTAT, 2015).

The values of production and amount of land allocated to production in the Apulia province are presented in Table 1. The data show that the *highest production* areas are in Bari and Lecce, but those with the *highest production intensity* are in the Brindisi-Andria-Trani (BAT) and Taranto regions.

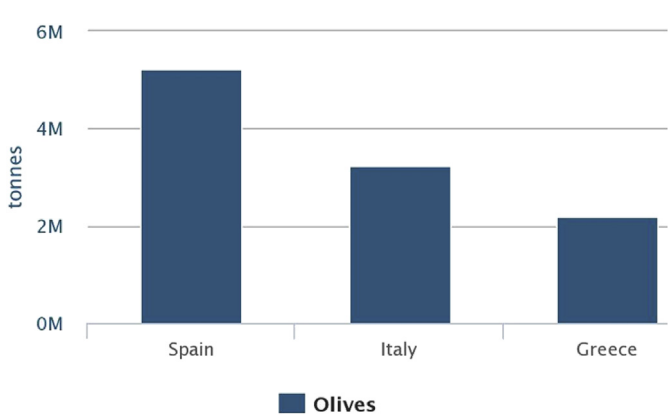

Fig. 5. Spain, Italy and Greece are the global leaders in the production of olives. The figures are average values during the period 1993–2013, expressed as t y^{-1}average. Source: FAOSTAT (2015)

Table 1
Agronomic data on Italian olive cultivation in six regions within the province of Apulia with a focus upon hectares of olive groves, their olive production and plant density (Agroquality, 2013).

Area	Surface (kha)	Production (kt)	Production intensity (t ha^{-1})
Bari	99.5	300.0	3.0
Lecce	90.5	233.7	2.6
Brindisi	63.6	189.0	3.0
Taranto	38.6	173.7	4.5
BAT	32.5	160.0	4.9
Foggia	52.5	157.5	3.0

In particular, the areas of Lecce and Brindisi are characterised by olive trees that are very old (the "secular" ones are up to 500 years old) and that contribute to outlining the regional landscape: they are protected by regional laws with the aim of reulating and limiting the uprooting of ancient, living trees. In this context, Table 2 presents the comparative strengths and weaknesses in the Apulia region production of the olives and in their processing into olive oil in the Apulia region (Agroquality, 2013).

From the analysis, it is evident that there are several options for the Apulian oil sector, but improvements are needed in the whole chain. This can be done through a series of important measures and investments oriented to:

- Updating production systems (using new technologies and logistical systems);
- Highlighting and improving tracking;
- Promoting greater penetration, especially in the international markets, based upon its good Geographic position.

Another important growth factor of producers' competitiveness in the global market is a greater and more widespread quality protection of olive oil based upon establishing and achieving quality standards.

Finally, several activities are increasingly being practiced for a more effective and targeted promotion, communication and information to protect consumers and to combat counterfeiting and adulteration of products.

5. Materials and methods

5.1. Description of the investigated olive growing systems

Olive tree (*Olea europaea* L. var. *sativa* Hoffm. and Lk.) is an evergreen species that is well adapted to the Mediterranean climate (Camposeo et al., 2011) and represents one of the most important resources for both economy and diet in the MR. As already anticipated, this crop has been historically part of the

Table 2
Strengths and weaknesses of olive production and transformation in the Apulian region (Agroquality, 2013).

Strengths	Weaknesses
Agricultural production	
Remarkable diversity of crops and the presence of suitable areas for both quantity and quality products	Fragmentation of the productive structure (reduced size of the olive farms)
High potential for the production differentiation (PDO/PGI)	The prevailing presence of traditional systems and limited diffusion of mechanisation and irrigation
High environmental, scenic, historical, cultural and anthropological values	Strong fluctuations in product quality
The possibility of stabilising the production, limiting the oscillations by streamlining and expanding irrigated areas	Very weak role of producer groups in the supply and improvement of product quality
Good image of the product for national and international consumers	Delay in the implementation of technological innovations
Processing and marketing	
Strong ability to penetrate foreign markets	Low level of vertical coordination
Strong image of the products from Apulia and generally of Made in Italy products	Use of the Made in Italy not coordinated at the production level
Broad base for procurement of raw materials	Presence in the foreign market of small businesses with the phenomenon of unfair competition
Consolidated expertise in the ability to meet the demands from foreign markets and distribution	Location of the mills is not always optimal
Globalisation of markets	Financial and logistical difficulties for compliance with current regulations.

agronomical, social and economic substrate of the area as one of the most important agricultural products, prominent for landscape added value and profit to farmers (Clodoveo et al., 2014; Nardino et al., 2013). In recent years, oil-olive orchard management have undergone extensive agronomic practice changes. Indeed, the olive tree cultivation system is increasingly changing: from traditional low-density (<200 trees per hectare) to modern medium-density (250–500 trees per hectare) and, mostly, to high-density (>1200 trees per hectare). According to Camposeo et al. (2008), the latter cropping system represents a very interesting approach to enhance olive orchard profitability, since it enables increased production per hectare while reducing the operating costs per kg of final product.

In the particular case, the olive groves under study are located in the surroundings of Valenzano (Bari, Southern Italy – 41°01′N; 16°45′E; 110 m a.s.l.), on a sandy-clay soil (sand, 630 g kg^{-1}; silt, 160 g kg^{-1}; clay, 210 g kg^{-1}) classified as a Typic Haploxeralf (USDA) or Chromi-Cutanic Luvisol (FAO). The site is characterised by a typical Mediterranean climate, with a long-term average annual rainfall of 560 mm (two third concentrated from autumn to winter) and a long-term average annual temperature of 15.6 °C (Camposeo et al., 2011). Three different olive cropping systems were compared: Traditional System (TS), Intensive System (IS), High-Density System (HDS). The former is based upon the rain fed growing of trees that are hundreds of years old and, therefore, this system is characterised by both low density and low productivity, thereby providing low economic returns for the growers. As documented by Godini et al. (2011), the latter aspect is also strictly due to the high costs for pruning, harvesting and poor marketing systems. In the analysed case, olive yield was equal to approximately 2.5 t ha^{-1} y^{-1}, which is between 1.5 and 3 t ha^{-1} y^{-1}, namely the typical range for such cropping systems. Moreover, as usually done in similar cases, harvest is manual or mechanised with the support of platforms, manual stem shakers and trunk shakers with reversed umbrellas for collection of the olives (Famiani et al., 2014; Sola-Guirado et al., 2014). In this regard, it was found that mechanised harvest technologies such as the canopy contact head harvesters are increasingly being utilised. This system improves efficiency of harvesting, because it facilitates olive collection and transfer into the trailers for transportation to the olive mills (Gil Ribes et al., 2012).

The intensive systems are the most common planting arrangements currently used by growers in modern orchards and are characterised by regular and medium-density cropping systems (Camposeo et al., 2008). In the analysed case, the grove had 400 trees per hectare, thus falling in between 250 and 500 units per hectare, which is the typical range for such growing systems. Moreover, good rates of productivity and mechanisation in the harvest phase were observed compared to the equivalent standards for such systems. The irrigation systems (drip irrigation, with an irrigation volume about 2000 m^3 ha^{-1} y^{-1}) resulted in an average yield of 10 t ha^{-1} y^{-1}, that falls within the typical range of 9–11 t ha^{-1} y^{-1} for such a cropping system (Godini et al., 2011). Harvesting was performed using mechanical tools such as, trunk shakers with several frames to collect the fruit, mainly for small orchards (less than 50 ha), or side-by-side shakers for large orchards (over 50 ha).

The High Density System was born in Spain in the '90s and has spread rapidly throughout the olive growing regions of the world. The diffusion of HDSs led to many studies designed to improve irrigation management and canopy growth (Vivaldi et al., 2013a,b; Strippoli et al., 2013), soil management (Camposeo and Vivaldi, 2011; Russo et al., 2014) and, harvesting activities in terms of time and yield (Camposeo et al., 2008, 2013). The system is based upon the rapid entry into production (3rd year) and the stabilisation of production from 6th to 7th year of the plant around 8–10 t ha^{-1} y^{-1} (Camposeo and Godini, 2010). There are three cultivars on which this system has been calibrated thus far: two Spanish, 'Arbequina' and 'Arbosana', and one Greek, 'Koroneiki' (Caruso et al., 2014; Camposeo and Godini, 2010; Godini et al., 2011). In the research area for this paper, both Spanish and Italian cultivars were introduced: the first ones are Arbequina', 'Arbosana', 'and Koroneiki'. In the case of the Italian varieties, the following groups were studied: traditional ('Carolea', 'Cima di Bitonto', 'Coratina', 'Frantoio', 'Leccino', 'Maurino') and patented ('Don Carlo®', 'Fs-17®', 'I/77®', 'Urano®') (Camposeo and Godini, 2010; Camposeo et al., 2012; Ferrara et al., 2012; Palasciano et al., 2008; Ferrara et al., 2007). For this grove, spacing of trees of 4.0 m × 1.5 m (1667 trees ha^{-1}) was implemented according to the Spanish HDS model. For the analysed HDS, olive production yield is almost 9 t ha^{-1} y^{-1}, so being in line with the typical rage for this system, namely 8–12 t ha^{-1} y^{-1} (Camposeo and Godini, 2010). The IR is approximately 1600 m^3 ha^{-1} under rain-fed conditions considering an average of 600 mm y^{-1} rainfalls: that value of IR was based upon Vivaldi et al. (2013a,b) who focussed upon the same groves. For all three systems studied, foliar fertilisation is performed by administering liquid fertilisers to be diluted in the irrigation water: the particular case, ammonium nitrate is used in the amounts reported in Table 3.

5.2. Goal and scope of the study

The study was designed to obtain detailed information about the WF of three different olive cropping systems using

Table 3
Amounts of ammonium nitrate used for grove fertilisation under the single growing system used in this research.

System	Ammonium nitrate (kg ha^{-1} y^{-1})
TS	440
IS	400
HDS	320

experimental data over the period 2009–2014, to highlight and to promote water usage efficiency improvements at the local and regional scale. The study was conducted for the following reasons:

- the olive sector plays an essential role in the culture, economy and diet of the Apulia region;
- huge amounts of olives, especially for transformation into oils, are produced every year in the region;
- the literature review revealed that no studies were done to compare the WFs of different olive growing systems.

Therefore, environmental studies are needed for improving efficiency and effectivity of water management so as to enhance overall improvement and valorisation of the sector.

Finally, the boundaries of the analysed system were outlined for the assessment and included not only the water consumed for the irrigation and fertilisation activities but also the virtual water (VW), also known as embedded water. According to Ridoutt et al. (2009), the latter refers to the total volume of freshwater used to produce a product or service, including water consumed in production and not physically present in the product. In the particular case, the VW is represented by the water consumed for production of the fertiliser utilised.

5.3. Methodology

In this study, WF assessment was performed accounting for the three water components (green, blue and grey) as established by Hoekstra et al. (2011). In particular, the blue-water accounting encompassed that of the VW, in order to be consistent with the objectives of the study. The latter was conducted to assess the freshwater usage associated with olive growing in three different systems, considering the last five years of the full production period. The research was possible due to the collaboration of local farms involved in providing the necessary agronomic data. In particular, data were collected from 2009 to 2014 with regard to ET_c, P_{eff}, as well as I_{eff}, and N-fertiliser consumption. For greater understanding, it was underscored that the period 2009–2014 was chosen as the reference for the assessment, because in the HDS the full production period started in 2009, thus making it possible to compare the three systems. Climatic data (ET_c and P_{eff}) were monitored at the agro-meteorological station of the village where all the farms are located, and supplied by the agro-meteorological office of the ASSOCODIPUGLIA. In particular, ET_c e P_{eff} were measured daily and, from the values recorded, the annual averages for each year in the period 2009–2014 were calculated, which was 123.07 mm y^{-1} and 550.22 mm y^{-1}, respectively. Then, the Crop Water Requirement (CWR) was calculated from both ET_c and the growing period length in days (lgp), according to equation (1):

$$CWR = 10 \times \sum_{d=1}^{lgp} ET_c \tag{1}$$

From calculation, a value of 120.37 mm ha^{-1} was so obtained.

As regards I_{eff} and the N-fertiliser amount, the corresponding values were listed in Table 4 for each system investigated. In particular, it should be observed that those relating to N-fertiliser refer to the active principle and were calculated from the amounts of ammonium nitrate listed in Table 3, based upon the N-content (equal to 35%).

Moreover, based upon CWR and P_{eff}, the IR was calculated as a constant value for the three systems according to equation (2) and resulted in 6534.63 m^3 y^{-1}.

$$IR = \max(0; CWR - Peff) \tag{2}$$

The aforementioned values were used for calculation of the three WF components (WF_{green}, WF_{blue} and WF_{grey}) following the approach outlined in the Water Footprint Manual provided by the WFN (Hoekstra et al., 2011). Then, the total water footprint (WF_{tot}), expressed as $m^3t^{-1}ha^{-1}$ y^{-1}, was calculated using equation (3):

$$WF_{(tot)} = WF_{green} + WF_{blue} + WF_{grey} \tag{3}$$

In the following section, the variables used to calculate each WF component are listed based upon the formula used by Hoekstra et al. (2011).

5.3.1. Green water

For WF_{green} accounting, the related evapotranspiration factor (ET_{green}) was calculated as the minimum between CWR and P_{eff}, so resulting to be equal to 550.22 mm. The latter was, then, used for calculation of the Crop Water Use (CWU_{green}) according to equation (4), so obtaining a value of 5502.17 m^3 ha^{-1}:

$$CWU_{green} = 10 \times \sum_{d=1}^{lgp} ET_{green} \tag{4}$$

For greater understanding, it is underscored that the obtained values of ET_{green} and CWU_{green} are the same for the three systems analysed, because the latter are located in the same cultivation area under monitoring and investigation. This means that no variation was recorded in the measured values of P_{eff} and ET_c and, in turn, in the CWR value as calculated according to equation (1). Finally, CWU_{green} was divided by the olive production yield (Y) for calculation of WF_{green}.

5.3.2. Blue water

As done for the WF_{green}, the blue WF component (WF_{blue}) was obtained dividing the CWU_{blue} by Y; hence, it was needed to calculate the value of CWU_{blue} from ET_{blue} using equation (5), as implemented below:

$$CWU_{blue} = 10 \times \sum_{d=1}^{lgp} ET_{blue} \tag{5}$$

where ET_{blue} was estimated from IR as the minimum between IR and I_{eff}.

For completeness reasons, Table 5 shows the values obtained for both ET_{blue} and CWU_{blue} which, as already clarified, are fundamental factors for calculation of WF_{blue}. For enhanced comprehension of the study, it should be noted from Table 5, both

Table 4
Values of I_{eff} and N-fertiliser used for WF calculation according to the methodological criteria discussed in this section.

Inventory data provided	Unit of measurement	Cropping system		
		TS	IS	HDS
I_{eff}	m^3 ha^{-1} y^{-1}	0	2000	1660
N-fertiliser	kg ha^{-1} y^{-1}	154	140	112

Table 5
Values of ET_{blue} and CWU_{blue} related to the irrigation phase, as resulting from application of equation (5).

System	ET_{blue} (mm)	CWU_{blue} (m^3 ha^{-1})
TS	0.00	0.00
IS	2000.00	20,000.00
HDS	1660.00	16,606.30

$ET_{blue} = 0$ and $CWU_{blue} = 0$ for the analysed TS: this is because TS is rain-fed and so $I_{eff} = 0$.

Furthermore, for each system the calculations were extended to the share of CWU_{blue} associated with the volume of water involved in the production of the ammonium nitrate utilised for fertilisation of 1 ha of grove: for convenience, that share was labelled as $CWU_{blue(fert.prod)}$. For this purpose, due to the difficulty of collecting primary data related to production of the fertiliser, Ecoinvent v.2.2 (Ecoinvent, 2011) data were used to extrapolate from the module contained, the amount of water to produce 1 kg of ammonium nitrate: that is equal to 4.671 m^3 $kg_{amm.nitr}{}^{-1}$.

This value was multiplied by the amount of ammonium nitrate per ha of grove (Table 3): the obtained $CWU_{blue(fert.prod)}$ values were shown in Table 6 per single system investigated. Hence, $CWU_{blue(tot)}$ was calculated by summing up the two contributions above, namely CWU_{blue} and $CWU_{blue(fert.prod)}$ and the values listed in Table 7 were resulted. They were then used for $WF_{blue(tot)}$ calculation, as clarified at the beginning of this section.

5.3.3. Grey water

As stated by Lamastra et al. (2014) referring to Hoekstra et al. (2011), calculations for water pollution in WFAs originated from the concept of a 'critical load' determining the assimilation capacity of a water body by multiplying the total water flow with the difference between the maximum and the natural concentration of a substance. In this regard, the grey WF was calculated using the following equation (6) as extrapolated from the WFA manual (Hoekstra et al., 2011):

$$WF_{grey} = \frac{NA \times \alpha}{(C_{max} - C_{nat}) \times Y} \times 1000 \quad (6)$$

where:

- NA stands for N-fertiliser application (kg ha^{-1} y^{-1});
- α is the nitrate leaching run-off fraction (constant) that was assumed to be equal to 0.1 (Dichio et al., 2014);
- C_{max} is the environmental water quality standard which was intended as the legal limit end-point of 15 mg L^{-1} (for nitrogen) as established by Italian Law Decree n. 152/2006 (MATTM, 2006).
- C_{nat} is the natural concentration in receiving water body, generally assumed to be 0;
- as already clarified, Y stands for the olive production yield, expressed as t ha^{-1} y^{-1}.

Table 6
Values of CWU_{blue}, related to (blue) water consumption for ammonium nitrate production: $CWU_{blue(fert.prod)}$.

System	$CWU_{blue(fert.prod)}$ (m^3 ha^{-1})
TS	2055.24
IS	1868.40
HDS	1494.72

Table 7
Values of $CWU_{blue(tot)}$ calculated as the sum of CWU_{blue} and $CWU_{blue(fert.prod)}$.

System	$CWU_{blue(tot)}$ (m^3 ha^{-1})
TS	2055.24
IS	21,868.40
HDS	18,101.02

6. Results and discussions

This section contains the discussion of the results gathered for each WF component estimation based upon measurements and calculations presented and discussed in the previous sections. The results were summarised and compared in Table 8, while the values of $WF_{(tot)}$, were calculated following equation (3) and depicted in Fig. 6.

Entering into the merits of WF_{blue}, Fig. 7 shows for each cropping system investigated the contributions from grove irrigation and ammonium nitrate production: in particular, the latter contribution was calculated dividing the values of $CWU_{blue(fert.prod)}$ in Table 6 by Y.

From Table 8, considering the values depicted in Figs. 6 and 7, there is evidence that when TS is rain-fed the greatest contribution to WF comes from the green component representing, indeed, 65% of $WF_{(tot)}$. In addition, WF_{blue} is attributed only with the amount of water embedded in the ammonium nitrate production that, being equal to 822.10 m^3 $t^{-1}y^{-1}$ represents almost 24% of $WF_{(tot)}$. On the contrary, for IS and HDS, $WF_{blue(tot)}$ results from both irrigation and fertiliser production, and is predominant compared to the green and grey components: indeed, it represents almost 77% and 74% of the related $WF_{(tot)}$ values. Also, for these systems the $WF_{blue(fert.prod)}$ represents nearly 9% of WF_{blue}, whilst only something in the range 6–7% with respect to $WF_{(tot)}$. As regards the grey-WF, this is largely higher in TS than in the other two systems due to the greater amount of fertiliser administered (Table 3). In particular, WF_{grey} represents in TS almost 12% of $WF_{(tot)}$, while comparable values were recorded for IS and HDS, representing around 3% of the estimated total-WF. Despite the differences related to soil and climate conditions, irrigation and fertilisation practices as well as VW accounting, the results were similar to those from the studies reviewed, in particular, with those by Amicarelli et al. (2011), Salmoral et al. (2011) and Dichio et al. (2014).

Finally, based upon results from the comparative assessment, HDS appears to be the less water demanding system, because it is characterised by the lowest irrigation volume (1660 m^3 ha^{-1} y^{-1}) and ammonium nitrate requirements (320 kg ha^{-1}) and the high yield (9 t ha^{-1}), which contributed to the lowest value for each of the WF component.

For contrast, the traditional system was found to be the most water demanding cropping system, mainly because it was grown with green water and a greater amount of ammonium nitrate was used for fertilisation compared to the other systems (Table 3).

However, in order to operate the comparison under the same background conditions and thus to contribute to enhanced

Table 8
Comparison of the WF components (green, blue and grey) in the analysed systems.

System	WF_{green}	WF_{blue}	WF_{grey}
	(m^3 t^{-1} y^{-1})		
TS	2200.87	822.10	410.67
IS	917.03	2186.84	93.33
HDS	687.77	2011.22	82.96

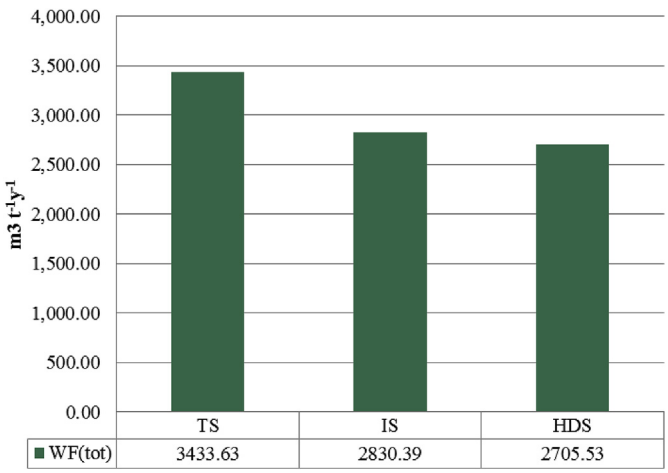

Fig. 6. WF_{tot} amounts for the growing systems analysed: TS under rain-fed conditions. Values are expressed as m^3 per tonnes of olive produced.

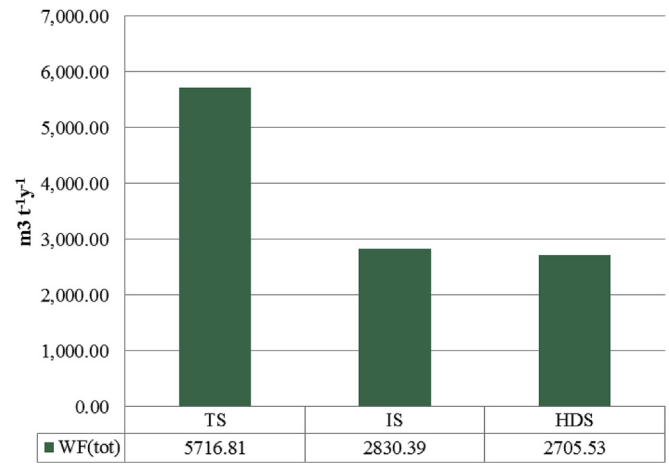

Fig. 8. $WF_{(tot)}$ amounts for the different growing systems: a comparison under TS irrigation conditions. Values are expressed as m^3 per tonnes of olive produced.

reliability and comparability of results, irrigation was assumed also for this system. Therefore, a sensitivity analysis was performed and is presented in the following section to show the subsequent change in the results.

6.1. Sensitivity analysis

In this analysis, the comparison was performed based upon the hypothesis that TS is irrigated and not rain-fed, so implying the accounting of the typical I_{eff} value (2000 m^3 ha^{-1}) for such systems (BURP, 2015) and the subsequent increase in the production yield. The latter doubles compared to that recorded in the case of non-irrigated TS, thus levelling out at almost 5 t ha^{-1}. This value was provided by the farm referring to TS olive groves located in other regional areas under the same soil and climate conditions and agricultural practices compared to the area under investigation. As shown by Fig. 8, the assumption made would cause an evident change in the results related to the traditional system, thus increasing the gap in WF terms compared to the other two systems (IS and HDS).

In particular, the following new values (expressed as m^3 t^{-1} y^{-1}) were obtained for WF-components in TS, considering the use of irrigation water and the increase in the production yield: 1100.43 (WF_{green}); 4411.05 (WF_{blue}); and, 205.33 (WF_{grey}). Results highlighted that, as a consequence of the irrigated-TS assumption, the new TS WF_{blue} (equal to 4411.05 m^3 t^{-1} y^{-1}) largely increased compared to the one previously obtained under rain-fed conditions and equal to 822.10 m^3 t^{-1} y^{-1} (see Table 8). For greater understanding, it is reminded that, as depicted in Fig. 7, the latter value was totally resulting from the accounting of the VW associated with the ammonium nitrate production. For contrast, both the green and grey components were reduced by approximately 50% compared to those recorded when TS is rain-fed, mainly due to the production yield increase: those components now represent nearly 20% and 4% of the TS WF_{tot}, respectively.

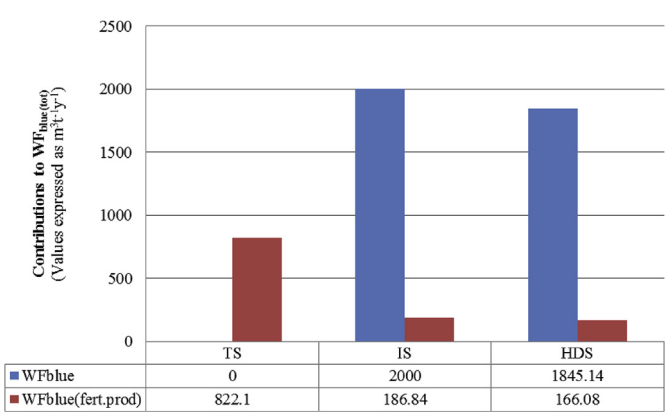

Fig. 7. The histogram reports a detailed comparison between the three systems in terms of the WF_{blue} contributions coming from the water consumed for irrigation and from that embedded in the fertiliser production (VW). Values are expressed as m^3 per tonnes of olive produced.

As a result, the $WF_{(tot)}$ related to the traditional system would be increased to approximately 5700 m^3 t^{-1} y^{-1} (Fig. 8), thus resulting in being almost two times higher compared to the $WF_{(tot)}$ values recorded for the other two systems, namely the intensive and the high density.

So, on the basis of the higher yield and the lower $WF_{(tot)}$, IS and HDS are both recommendable to be implemented for production of olives for transformation into oils and derivatives. In particular, the analyses documented that these two cropping systems are quite comparable in terms of $WF_{(tot)}$. Therefore, the authors believe that any further decision about the cropping system to be promoted should be made based upon results from detailed economic analyses, which must also account for management costs and income of growers from olive sales.

7. Conclusions and recommendations

Water footprint evaluations are very important, because they contribute to product and business transparency, thereby providing to consumers the support needed for making well-informed decisions. Also, WF accounting constitutes good economics in agriculture, because water is such an essential resource that must be properly managed throughout the whole food supply chain.

In this context, the research results provided insights into the comparative WF performance of three different density olive producing systems. The authors hope that the results will be useful to support the stakeholders involved (i.e. agronomists, farmers, company owners and policy makers) in decision-making for promotion of improved olive cultivation and production of derivatives by more eco-friendly agricultural and industrial processes.

The systems characterised as high density plantations were found to be more efficient in terms of WF_{tot}. Based upon the

findings, HDS is the less water demanding system also under irrigation conditions for all the three systems analysed. Moreover, the main WF_{tot} component is blue water, representing almost 77% of $WF_{(tot)}$ for TS and IS, whilst 74% for HDS: lesser contributions were derived from WF_{green} and WF_{grey} for all of the three systems.

The excellent cooperation of the olive grove owners enabled the researchers to gather high-quality data, thereby making it possible to develop a scientific-value study that provided reliable and relevant insights. In this regard, the targeted stakeholders (environmental assessment practitioners, agronomists, farmers and company owners) may learn more about the input flows involved in the systems analysed and the related WF rates. In this way, the research-study contributes to enriching the international knowledge on the field, and underscores the potential value of comparative WF analyses in the olive production sector for enhanced water resource management. For better understanding and appreciation of the study, it is underscored that its conclusions relate to the system investigated, to the insights gained, as well as to the growing practices and to the input data used. The researchers are convinced that the insights gained from this research will contribute to the WF approach in this agricultural sector.

Based upon the findings, it can be concluded that the HDS is the most competitive system due to reduced $WF_{(tot)}$ and to high agronomic and economic-efficiency rates. The authors believe that this system could be used as the starting base for implementation of agricultural practices aimed at WF reduction, improved environmental sustainability and management cost optimisation in the olive sector.

The study made it possible to highlight the importance of similar comparative studies at local scales for improved efficiency of different orchard systems in managing water sources. Such information could be combined with surveys on other fundamental aspects (socio-economic, environmental), and therefore could be a valuable starting point for beginning to draft guidelines for the best orchard management in accordance with environmental policies.

Finally, the study may contribute to enhancing knowledge on the applicability and usefulness of foot-printing tools for enabling more environmentally sustainable agricultural systems by encouraging productive usages that focus upon improving efficiency of the production processes.

Acknowledgements

The authors would like to thank the olive production farmers for their excellent collaboration with the research group by providing data and information, as needed for the study development.

The article has been thought, discussed and written by the six authors and is the result of their common commitment; in particular: *Miss. Giustina Pellegrini* and *Dr. Carlo Ingrao* have dealt with the planning, implementation and development of the research, as well as with the writing of most of this document; *Prof. Caterina Tricase* has dealt with olive production data collection and discussion; *Prof. Salvatore Camposeo* has contributed to agronomic data collection and to the writing of the conclusion section; *Prof. Francesco Contò* has dealt with global revision of the article.

Finally, the authors are highly grateful to *Prof. Donald Huisingh* for his multiple contributions in supervising paper set-up and development as well as in reviewing the final version of the paper.

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