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Water Footprint Score: A Practical Method for Wider Communication and Assessment of Water Footprint Performance †

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Abstract: In the present study, we propose a simple and practical method for assessing and communicating Water Footprint (WF) performance of a crop. We introduce the concept of "Water Footprint Score" (WFS), a comprehensive and comparable indicator of farmers' water resources management performance, which can be incorporated into agricultural products' labels. WFS as the outcome of the comparison with a water footprint annual reference level, and is a spatiotemporally comparable metric that reflects the convergence to best cultivation practices and can be easily perceived by both farmers and consumers. Examples of water footprint score for two different crops, kiwifruits and table olives, are provided.

Keywords: water footprint annual reference level; water footprint labeling; kiwifruit; table olives

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1. Introduction

Water Footprint (WF) as a metric of water consumption and pollution along the production chain of a good or a service [1] has evolved during the last two decades into a popular environmental indicator and a valuable tool for water management schemes' development at many levels. Since its first introduction in 2002, numerous WF assessments have been carried out [2,3], providing a large database of product, process and service water footprints. Its application in agriculture, a major water user, provides a clear indication of global crop water consumption and pollution patterns.

Despite its popularity among scientists and policy makers, slower uptake has been noticed at the farmers' and consumers' levels [4], probably due to the significant spatiotemporal variability of WF values that affect its comparability. At the field level, WF computation and further analysis of its components is valuable for farmers, since it provides an explicit insight into the general water management pattern followed, such as the degree of rainwater exploitation as a means of fresh water saving or the degree of water pollution caused by irrational agronomic practices related to fertilization and plant protection. The question that usually arises after computing the WF of a crop is the actual meaning of the WF value as far as further action and response formulation are concerned. Mekonnen and Hoekstra [5] proposed the comparison of a WF of a crop with reference levels of WF and for that reason they have developed global WF benchmark values for crop production. However, although global benchmarks are significant tools for the design and implementation of global policies, at the farmers' level they do not offer practical normalized information since site-specific climatic conditions, soil nutrients and plant health status affect applied agronomic practices depicted in WF computations, and thus the results are not fairly comparable.

Communication of WF to the wider public is a core issue in the growing global market of green products. Water footprint labeling as proposed by Hoekstra et al. [1] can either include the total WF of the product and/or the specification of its components, the degree of environmental sustainability achieved or the volume of water consumption compared to a reference year. The above either offer little or incomplete information regarding applied cultivation practices, require further analysis in order to be comprehensive, or lack comparability. Consumers need to be provided with complete and comprehensive information in order to "reward" farmers' actions towards sustainable water management.

The objective of the present study was to develop a simple and practical method for assessing and communicating in a single score WF performance of an agricultural product at the field level. We introduce the concept of "Water Footprint Score", a comprehensive and comparable indicator of farmers' water resources management performance, which can be easily incorporated into agricultural products' labels.

2. Methodology

2.1. General Concept and Approach

The general approach of the proposed method is to develop a comparable metric that depicts the performance of the applied cropping management practices. Two new terms are introduced:

- Water Footprint Score (WFS), which is proposed as a single score indicator of this performance. It expresses the result of the comparison of the WF of a crop with the WF that could be achieved if the farmer applied the optimal cultivation practices;
- Annual Reference Level of Water Footprint (WF′) is introduced as the WF of a certain crop for a certain period that would be achieved if rational cultivation practices were applied at the specific site.

In this way farmers can have a more realistic depiction of how much their agronomic practices distance from the best applicable agronomic practices in the specific spatiotemporal context and not general best agronomic practices, which could be significantly differentiated by site-specific factors. The proposed method aims to provide an effective tool towards adoption of realistic sustainable agronomic practices.

2.2. Standard WF Computation Method by Hoekstra et al.

According to the Water Footprint Assessment Manual [1], the WF of a crop is computed as the sum of three distinctive components that reflect water use and pollution per unit of crop along the entire agricultural process: the green water footprint (WF_{green}), which refers to the amount of rainwater (green water) consumed during the growing period of a crop; the blue water footprint (WF_{blue}), which is linked to the consumption of surface and ground water (blue water); and the grey water footprint (WF_{grey}), which quantifies pollution caused by the application of fertilizers and pesticides and is expressed as the volume of fresh water needed to assimilate this pollution. WF components are computed as Equation (1):

$$WF_{green} = \frac{10 \times \sum_{d=1}^{lgp} ET_{green}}{Y} \quad (1)$$

$$WF_{blue} = \frac{10 \times \sum_{d=1}^{lgp} ET_{blue}}{Y} \quad (2)$$

$$WF_{grey} = \frac{\frac{\alpha \times AR}{c_{max} - c_{nat}}}{Y} \quad (3)$$

where ET_{green} and ET_{blue} (mm) are respectively the green and blue evapotranspiration during the length of the growing period (lgp), which measure the actual water consumption of a crop and if multiplied by ten (10) are expressed in $m^3\ ha^{-1}$; Y is the crop yield ($t\ ha^{-1}$); α is the leaching factor of the pollutant; AR is the application rate of the pollutant; and c_{max} and c_{nat} are the maximum allowable and the natural concentration of a pollutant in a certain site, respectively.

2.3. Annual Reference Level of Water Footprint

As mentioned above, the annual reference level of a crop's water footrpint is defined as the WF of a certain crop for a certain year at a certain site that would be achieved if optimal cultivation practices were applied.

Optimal cultivation practices regarding irrigation refer to the maximum possible exploitation of rain so that additional irrigation is applied only in the case that effective rainfall cannot meet actual crop water needs as expressed by actual evapotranspiration. Effective rain is defined as the rain that is stored in the soil and remains available to be used by the crop. Exploiting the maximum of the effective rain means that the volume of irrigation water applied to the crop is the minimum possible. This in turn means that maximum level of freshwater saving has been achieved.

Optimal cultivation practices regarding fertilization refer to two possible conditions: either the effective application of rational fertilization based on actual crop needs as determined by soil analysis, which would lead to the minimization of grey water footprint, or the application of organic fertilization, which in this case would lead to zero WF_{grey}.

The annual reference level of water footprint is calculated for green, blue and grey WF.

Hoekstra et al. proposed two methods for ET_{blue} and ET_{green} estimation using the CROPWAT model [1]: the Crop Water Requirements (CWR) option, which assumes optimal conditions and even though it is not very accurate it is employed when no irrigation data are available; and the irrigation schedule option, which is more accurate since it takes into account climate, soil and crop data along with irrigation data in order to calculate actual evapotranspiration (ET_a) using the daily soil water balance approach. While the first option provides the optimal rain water exploitation and thus defines the lowest potential irrigation needs, the second option estimates the real rain water exploitation, defining the actual part of irrigation that covered crop water needs (ET_{blue}).

In the present work's proposed WFS method, actual blue and green WF (WF_{green} and WF_{blue}, respectively) considers actual ET_{green} and ET_{blue} estimation based on the irrigation schedule option specifying the actual irrigation practice, selecting "irrigate at user-defined intervals and application depth" in the CROPWAT model.

The annual reference level of green and blue WF (WF'_{green} and WF'_{blue}, respectively) considers optimal rain water exploitation and thus optimal green and blue ET (ET'_{green} and ET'_{blue}, respectively), which are estimated based on the crop water recuirement option according to [1] as:

$$ET'_{green} = \min\,(ET_c, P_{eff}) \tag{4}$$

$$ET'_{blue} = \max\,(0, ET_c - P_{eff}) \tag{5}$$

Alternatively, ET'_{green} and ET'_{blue} can be estimated by applying the irrigation schedule option in the CROPWAT model by selecting "irrigate at critical depletion".

The annual reference level of green and blue WF are calculated according to Equations (1) and (2) subsituting ET_{green} and ET_{blue} with ET'_{green} and ET'_{blue}, respectively (Equations (4) and (5)).

The annual reference level of grey WF (WF'_{grey}) is calculated according to Equation (3) applying for AR the quantity of fertilizer that meets plant needs as determined by soil analysis results. In the case of the application of lower quantities of fertilizers than needed, WF_{grey} is considerd to be equal to WF'_{grey}. In the case of organic cultivation, WF_{grey} is zero.

Regarding yield (Y), for simplification reasons actual crop yield achieved is taken into account so as to avoid considering additional factors that are not entirely related to the agronomic practices applied and thus are not subjected to farmers' control. Additionally, this customized approach normalizes performance and facilitates comparisons.

2.4. Water Footprint Score

The Water Footprint Score (WFS) expresses a crop's WF performance in two major cultivation practices: water management and fertilization, and is defined as the result of the comparison between the actual crop's WF and the annual reference level of the crop's WF

(WF′). Since WF_{blue} only accounts for the volume of irrigation water actually consumed by plants and not the full volume of irrigation water applied, the magnitude of convergence from the best irrigation practice is better described by the ratio WF_{green}/WF_{blue}, which is considered to be a more indicative depiction of irrigation management performance as it encompasses the rainwater exploitation rate. For that reason, instead of comparing the WF_{green} and WF_{blue} with the respective WF'_{green} and WF'_{blue}, the ratio of actual green to blue WF is compared with the ratio of the annual reference level of green and blue WF as:

$$WFS_{green/blue} = 100\% \times \frac{WF_{green}}{WF_{blue}} \Big/ \frac{WF'_{green}}{WF'_{blue}} \tag{6}$$

Actual WF_{grey} is compared to the of annual reference level of WF_{grey} as:

$$WFS_{grey} = 100\% \times \frac{WF'_{grey}}{WF_{grey}} \tag{7}$$

According to this approach, the value of WFS consists of two parts:

- $WFS_{green/blue}$, which reflects water management performance (the ratio of green to blue WF);
- WFS_{grey}, which reflects the fertilization performance (WF_{grey}).

Higher values are associated with better performance. Values equal to 100 for each part indicate excellent WF performance while lower values indicate lower WF performance.

2.5. WFS Labeling

Following the WFS calculation, WFS performance is classified according to three major classes for each component as proposed in Table 1:

Table 1. WFS performance classification.

A (Excellent)	B (Medium)	C (Poor)
100–70	69–30	29–0

WFS classification is proposed as a WFS labeling option, which can explicitly communicate to the consumer a product's WF performance. WFS labeling can offer a quick visualization of the performance in each of the two main agronomic practices, irrigation and fertilization. For this reason, WFS can be expressed with two letters that represent performance in each of the two agronomic practices assessed. For instance, a $WFS_{green/blue}$ of 95% and WFS_{grey} of 22% can be classified as WFS = AC and visualized as (Figure 1):

Figure 1. Visualization of WFS score.

3. Case Studies: Kiwifruit and Table Olive Water Footprint Score

We performed a WFS computation for two major crops in the plain of Arta (Northwestern Greece), kiwifruit and table olive, for the year 2022.

3.1. Materials and Methods

The climate in the area is of a Mediterranean type with moderate rainy winters and dry, hot summers. Average annual temperature is 17.2 °C and annual precipitation is about 1100 mm. The water footprint score was calculated for the growing period of 2022 for a 10 year-old kiwi orchard and a 40 year-old table olive orchard. The kiwifruit orchard covers an area of 10 ha and the plant density is of 650 vines ha^{-1}. The table olive grove covers an area of 0.2 ha and the plant density is of 250 trees ha^{-1}. Meteorological data for the estimation of ET_c were provided by the net of agrometeorological stations established in the plain of Arta by the Department of Agriculture of University of Ioannina [6]. Farmers provided agronomic data such as application rate of fertilizers (AR) and yield (Y). The leaching factor (α) was set at 0.1 [1], c_{max} was set at 50 mg NO_3 L^{-1} (or 11.29 mg N L^{-1}) according to the EU Nitrates Directive, 91/676/EEC and c_{nat} was assumed to be zero [1]. In both orchards, irrigation and fertilization were performed based on farmers' experience. Table 2 summarizes agronomic data regarding the applied net irrigation, fertilization and final crop yield of the two fields.

Table 2. Agronomic data of kiwifruit and table olive orchard.

Field	Applied Net Irrigation (mm)	N-Fertilization (kg ha^{-1})	Yield (t ha^{-1})
Kiwifruit orchard	1114.40	325.10	35
Table olive grove	398	293	17

For both fields, WFS was calculated following the methodology described in the previous section and applying Equations (6) and (7).

3.2. Results and Discussion

According to Equations (6) and (7), in order to calculate WFS we need to calculate the actual WF and the annual reference level of WF components.

Actual WF components (WF_{green}, WF_{blue} and WF_{grey}) were calculated according to the typical method [1] and ET_{green} and ET_{blue} were estimated based on the soil water balance as modeled by CROPWAT [4] when applying the "Irrigation Schedule" option. Table 3 summarizes the actual ET_{green}, ET_{blue} and WF components for the two fields.

Table 3. Actual ET_{green}, ET_{blue} and WF components.

Field	ET_{green} (mm)	ET_{blue} (mm)	WF_{green} (m^3 t^{-1})	WF_{blue} (m^3 t^{-1})	WF_{grey} (m^3 t^{-1})
Kiwifruit orchard	38.78	778.28	11.08	222.37	84.44
Table olive grove	274.6	143.4	161.52	81.76	152.65

The annual reference levels of green and blue WF were computed according to Equations (4) and (5). N-application rate was determined by the soil analysis performed as 182 and 127 kg ha^{-1} for the kiwifruit and table olive, respectively. Table 4 summarizes the annual reference levels of WF components for the two fields.

Table 4. Annual reference levels of ET_{green}, ET_{blue} and WF components.

Field	ET'_{green} (mm)	ET'_{blue} (mm)	WF'_{green} (m^3 t^{-1})	WF'_{blue} (m^3 t^{-1})	WF'_{grey} (m^3 t^{-1})
Kiwifruit orchard	149.78	667.28	42.79	190.65	47.27
Table olive grove	303.2	114.8	178.23	67.06	66.17

The WFS of the two fields was calculated according to Equations (6) and (7):

For the kiwifruit orchard:

$$WFS_{green/blue} = 100\% \times [(11.8/222.37)/(42.79/190.65)] = 22\% \tag{8}$$

$$WFS_{grey} = 100\% \times (47.17/84.44) = 56\% \tag{9}$$

The WFS of the kiwi orchard was classified as (Figure 2):

Figure 2. WFS label for the specific kiwi orchard.

For the table olive grove:

$$WFS_{green/blue} = 100\% \times [(161.52/81.76)/(172.23/67.06)] = 74\% \quad (10)$$

$$WFS_{grey} = 100\% \times (66.17/152.65) = 43\% \quad (11)$$

The WFS of the table olive orchard was classified as (Figure 3):

Figure 3. WFS label for the specific table olive orchard.

For the kiwifruit, performance of both practices (irrigation management and fertilization) was poor to medium. In the case of the table olives, irrigation management proved to be better although fertilization practice was medium. Farmers could achieve a better water management performance through the maximum exploitation of rainfall and applying irrigation based on actual crop's needs. Monitoring soil moisture with sensors and using DSS systems for irrigation are proven to be effective means towards rational irrigation. Regarding fertilization, rational application practice is based on the determination of plants' actual nutrient needs through the performance of soil analysis.

4. Conclusions

The water footprint score is a simple and practical method to assess water footprint performance evaluating the main agronomic practices applied in a crop that have a large impact on the environment: irrigation and fertilization. WFS captures, in a single number, hotspots of agronomic practices and focuses on the specific agronomic practice that needs improvement. Farmers can use the WFS in order to understand how they performed compared to what they could actually do in order to apply sustainable practices at a realistic level. WFS points out which of their agronomic practice is environmentally costly in order to take action towards the specific direction. Additionally, WFS is a practical method to communicate farmers' performance to the wider public. Consumers can have a clear and comprehensive view on a product's "history", facilitating in this way their choice.

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