
A preliminary study on a new approach to estimate water resource allocation: the net water footprint applied to animal products

Alberto Stanislao Atzori*, Caterina Canalis, Ana Helena Dias Francesconi, Giuseppe Pulina

Dipartimento di Agraria, University of Sassari, Viale Italia, 39, 07100 Sassari, Italy

Abstract

We propose the Net Waterfootprint (WFPnet) method to estimate the water footprint (WFP) of food products, in alternative to the current WFP method, based on absolute values. We compared the WFP and WFPnet methods for cattle milk and meat production in different feed efficiency (high and low) and crop water use efficiency (WUE; high, medium and low) scenarios under Mediterranean conditions. The WFP values were, on average, much higher than the WFPnet values for both meat and milk. The WFPnet method appears to be able to properly quantify the water consumption needed for animal food production.

© 2016 The Authors. Published by Elsevier B.V. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).
Peer-review under responsibility of Fondazione Simone Cesaretti

Keywords: Evapotranspiration; water use efficiency; milk; meat; ecological footprint; livestock; cattle; environment; crop; ruminant

1. Introduction

Agriculture accounts for 92% of the world’s water consumption (Hoekstra and Mekonnen, 2012a). Among foods, animal products are considered to be the highest consumers of water (Mekonnen and Hoekstra, 2012). The reduction in the pressure on water resources from food products is a major challenge for humanity, and knowledge of water consumption is relevant for national governments to plan and assess their environmental policy and food security (Hoekstra and Mekonnen, 2012b).

Water FootPrint (WFP) is an indicator that measures the quantity of water used for the production of a unit of
goods or services, looking at both direct and indirect water use of a consumer or producer (Hoekstra et al., 2011). The main approaches to calculate WFP are based on the Water Footprint Network (WFPN; e.g. Hoekstra et al., 2011; Water Footprint Network, 2015) and the Life Cycle Assessment (LCA; e.g. Ridoutt and Pfister, 2010; De Boer et al., 2013) methods. Some authors account for blue water only, such as Hoekstra and Hung (2002) for WFPN and Ridoutt et al. (2010, 2012) and De Boer et al. (2013) for LCA, whereas others recommend including also green water data to calculate WFP (Falkenmark and Lannerstad, 2005). The blue water is the fresh surface water and groundwater (freshwater lakes, rivers and aquifers); the green water is the rainwater stored in the soil or remaining temporarily on the soil top or vegetation, which eventually evaporates or transpires through plants; and the grey water is the polluted part of the used water (Hoekstra et al., 2011).

The WFP of animal products is expressed as the volume of freshwater (good quality water) used to produce a kg of product. In the livestock sector, the sum of blue and green water used to produce feeds accounts for more than 99% of the total consumed water (Brown et al., 2009; Pulina et al., 2011). Until now estimations of WFP of animal products using the WFPN and the LCA methods have been hardly comparable (Table 1). Vanham and Bidoglio (2013) made a critical review on the volumetric WFP methodology used by the WFPN, showing that the development of the WFP concept is still incomplete. The LCA method also has some limitations related to its focus on blue water only. Therefore, the methodology of calculation of WFP has a large impact on the final calculated values and needs to be improved in order to obtain comparable results and plan effective mitigation strategies.

### Table 1. Comparison between calculations of the water footprint of animal products using the Life Cycle Assessment (LCA) and the Water Footprint Network (WFPN) methods.

<table>
<thead>
<tr>
<th>Authors</th>
<th>Method</th>
<th>Product</th>
<th>Water Footprint</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Irrigated Farms</td>
<td>Rainfed Farms</td>
</tr>
<tr>
<td>Ridoutt et al. (2010)</td>
<td>LCA (Water deprivation)(^1)</td>
<td>1 kg Milk</td>
<td>1.9 L H(_2)O(^2)</td>
</tr>
<tr>
<td>Ridoutt et al. (2012)</td>
<td>LCA (Water deprivation)(^1)</td>
<td>1 kg Beef Cattle LW(^3)</td>
<td>3.3-221 L H(_2)O(^2)</td>
</tr>
<tr>
<td>De Boer et al. (2013)</td>
<td>LCA (Consumptive water use)</td>
<td>1 kg FPCM(^4)</td>
<td>66 L H(_2)O</td>
</tr>
<tr>
<td></td>
<td>LCA (Water deprivation)(^1)</td>
<td>1 kg FPCM(^4)</td>
<td>16 L H(_2)O</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>33 L H(_2)O(^2)</td>
</tr>
<tr>
<td>Mekonen and Hoekstra (2012)</td>
<td>WFN</td>
<td>1 kg Milk</td>
<td>1000 L H(_2)O</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1 kg Beef</td>
<td>15400 L H(_2)O</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1 kg Eggs</td>
<td>3300 L H(_2)O</td>
</tr>
<tr>
<td>Chapagain and Hoekstra (2004)</td>
<td>WFN</td>
<td>1 kg Chicken meat</td>
<td>4300 L H(_2)O</td>
</tr>
</tbody>
</table>

\(^1\) Water deprivation is the net reduction in the amount/availability of freshwater in a watershed or/and an aquifer.

\(^2\) L of H\(_2\)O equivalents/kg of product, obtained by multiplying each value of consumptive water use by the relevant water stress index (WSI; Pfister et al., 2009), summed up for the entire production cycle and normalized, by dividing it by the global average WSI.

\(^3\) Live Weight.

\(^4\) Fat and protein corrected milk.

The green water is often considered less important than the blue and grey water, because it normally generates low, or even negligible, opportunity cost. However, among food products, green water is the main component of the WFP. Many authors have considered the total evapotranspiration (ET) when calculating the green water using the WFPN method (e.g. Rost et al., 2008), but the ET related to the grass actually consumed was taken into account.
rather than the total ET for grazing lands (Mekonnen and Hoekstra, 2012).

In our opinion, the green water should be included in the calculation of the total WFP, considering that the ET of crops and pastures is the main way in which water from soil and plants goes back to the atmosphere. From a holistic point of view, the ET in a typical land will occur even in the absence of production or in the presence of natural vegetation cover. Thus, based on the principle of alternative opportunities, we believe that the amount of green water of a certain food product should not be considered in absolute terms. Instead, it should be calculated considering the differential evapotranspiration ($\Delta ET$) between the total ET of a crop or pasture assessed for the WFP calculation and the ET of a hypothetical scenario (e.g. forestland or shrubland) of a natural cover on the same land surface. Therefore, we propose a new method to estimate the WFP of food products, named **Net Waterfootprint (WFPnet)**, in alternative to the actual concept of WFP of a product, usually expressed in absolute terms.

This paper compared the estimations of the WFP method and the new WFPnet method for cattle milk and meat production within a biological range of production efficiency in a Mediterranean scenario.

2. Materials and Methods

2.1. Initial considerations for the calculation of Net Waterfootprint (WFPnet)

The WFPnet considers that blue water should be definitely included in the calculation because it represents the water to be supplied to the target production process. The WFPnet also states that the green water should be taken into account for WFP estimations, and should be calculated subtracting from the water consumed by a cultivated crop the amount of water consumed by a spontaneous natural cover (forestland or shrubland) that would take place in the same area if the crop were stopped. In fact, the evaporation from these lands would occur even in the absence of crop production.

The green water consumed by a given crop, mainly composed of rainfall and soil storage, can be estimated similarly to the water evaporated from the area of a given crop. Therefore, the crop water consumption can be considered approximately equal to the ET, being negligible the rainfall water intercepted by the plants and soil evaporation (Nisbet, 2005; Katerji et al., 2008). Recent agronomic studies highlighted that, from a policy point of view, WUE, expressed as kg of crop biomass/L of water, can be a more useful measure of water resource consumption than ET per se because it refers to the effectiveness of the available resource for human purposes (Hatfield et al., 2001). The WUE (kg of biomass/L of water) can be calculated as follows:

$$WUE = \frac{Yield}{Water\ consumption\ or\ ET},$$

where yield is the actual marketable crop yield (kg/ha), water consumption is the amount of water consumed during the crop cycle (m$^3$/ha), and ET is the actual crop water consumption by evapotranspiration (m$^3$/ha).

Focusing on food production, the yield of cultivated areas can be destined to human nutrition either directly or indirectly, the latter occurring when cultivated products are consumed by livestock or wild species and humans take advantage of the nutrients provided by animal products. In this sense, the yield of a land area not covered by cultivated crops and not involved in livestock or hunting activities can be considered equal to 0. The water consumption of a land area depends on the vegetation and climate characteristics. In particular, ET is often higher for forests than for rainfed crops (Nisbet, 2005). In Mediterranean areas, where precipitations range between 400 and 1000 mm/year, ET of oak woodlands ranged from 350 to 600 mm/year, reaching ET values higher than precipitation in very dry areas or arid periods (Baldocchi and Xu, 2007), whereas WUE ranged from 0.11 to 2.8 kg of marketable yield/m$^3$ of water consumed (rain + irrigation) for cultivated crops with a dry matter content higher than 80% (Katerji et al., 2008) and showed values of 3.0 and 3.4 kg of marketable yield/m$^3$ of water consumed for dry alfalfa and irrigated corn silage, respectively (Dono et al., 2013).

In this study, a comparison of WFP and WFPnet methods was performed for cattle milk and meat scenarios, as presented below.
2.2. Calculation of the Water Footprint (WFP) and the Net Water Footprint (WFP$_{\text{net}}$)

The water footprint (WFP) can be calculated with the following formula:

$$\text{WFP} = \text{water for feed production (green + blue)} + \text{drinking water (blue)} + \text{servicing water (blue)}$$

where water for feed production (green water + blue water) is equal to the water consumed by the crops (rain water, soil water and irrigation) needed to produce the animal feeds, being equal to ET (m$^3$/ha); the drinking water is the water drunk by the animals; and the servicing water is the remaining water consumption in the farm for other animal needs and facilities.

The net water footprint index proposed in this paper calculates the water consumed to produce an animal product considering that the system boundaries are within farm gate. Based on the initial considerations reported above, the net water footprint index (WFP$_{\text{net}}$) can be calculated as the amount of water consumed in a generic production process of meat and milk, considering the additive contribution of the green and blue water as follows:

$$\text{WFP}_{\text{net}} = [\text{consumed biomass for each type of feed used/WUE of the crop} \times (\text{green} + \text{blue})] - \text{virtual water of the natural cover replacing the crop (green)} + \text{drinking water (blue)} + \text{servicing water (blue)}$$

where the first term represents the water for feed production (green water + blue water), which is the water consumed by crops including rain water, soil water and irrigation supply, being equal to ET (m$^3$/ha); the virtual water of the natural cover indicates the evapotranspiration (ET; m$^3$/ha) of a natural cover that would replace the considered crop in the same land surface if crop production were abandoned, representing an opportunity cost of the system; the drinking water is the water drunk by the animals; and the servicing water is the remaining water consumption in the farm for other animal needs and facilities.

2.3. Scenarios for WFP and WFP$_{\text{net}}$

The water footprint and the net water footprint index were calculated for typical scenarios of milk or meat production, with different levels of feed efficiency and WUE of an irrigated crop. High feed efficiency referred to a typical farm using specialized breeds for milk or meat production and/or having highly efficient animal management practices, with low feed dry matter intake (DMI) per unit of milk and meat produced. Low feed efficiency referred to the use of dual purpose cattle breed and/or poor management practices at farm level, thus leading to lower animal performance, i.e., a high feed dry matter intake (DMI) per unit of product. For each of those 4 scenarios, we assumed typical animal performance and dietary composition data. Considering the most common conditions of specialized production areas in the Mediterranean region, we assumed that forages and grain were produced from rainfed and irrigated lands. To simplify, we assumed that grains from irrigated lands were corn grains, for which the three possible levels of WUE were simulated. In total, 12 scenarios of WFP and WFP$_{\text{net}}$ values were calculated for the different combinations of 2 products, 2 levels of feed efficiency (i.e., animal performance) and 3 levels of corn crop WUE (Table 2).

Calculation assumptions for animal products

For estimates of both WFP and WFP$_{\text{net}}$, high feed efficiency for meat production was assumed to have 20 kg DMI per kg of meat produced, assuming 6000 kg of DMI (for the entire cycle of the cow-calf and growing finishing phases) and 300 kg of carcass weight as reported for Italian beef cattle by FAOSTAT (2013). Low feed efficiency was set to have 30 kg DMI per kg of meat and assuming 7500 kg of DMI for the entire cycle and a carcass weight of 250 kg for a less efficient system (Table 2).

High and low feed efficiency for milk production were set to have 0.75 and 1.30 kg of DMI by the herd per kg of milk sold for a milk yield of 9000 and 5500 kg of milk per year per head, respectively (Table 2), as previously observed in a sample of 285 dairy farms surveyed for carbon footprint estimation in Southern Italy (Atzori et al., 2013).
Using those parameters, water consumption for drinking and services, expressed as L per unit of product, was calculated based on Brown et al. (2009) as already used by Pulina et al. (2012) for similar estimations. Animal diets were estimated considering typical feeding practices for the considered categories to obtain the required amounts of forages and concentrates produced in rainfed and irrigated lands. Reference rainfed forages were pasture and grass, forages from irrigated lands were assumed to be corn silage and alfalfa, and the reference grain from irrigated lands was assumed to be corn grain.

Calculations assumptions for crops destined to animal feed

Yields and water consumption for reference crops were gathered from Dono et al. (2013) and Katerji et al. (2008) to calculate the consumed water and the WUE for each feed category. Furthermore, three possible scenarios were hypothesized for corn grain production considering a high, medium and low WUE (from 1.38 to 8.00 kg of product per m³). The lowest WUE considers unfavourable conditions and bad practices, whereas the highest WUE refers to forecasted future agronomic techniques (soil, fertilizers, water management, genetics, etc.) for cultivated crops. Water consumed by natural cover of forest land and shrubland was assumed to be equal to 3500 m³/ha, which were the lowest values suggested by Baldocchi and Xu (2007) in order to maintain a conservative approach in the estimation of WFPnet.

In order to obtain the values of blue water and green water consumption, expressed as litres of consumed water per kg of animal product, calculations were done separately for irrigated and rainfed forages and grains used for feed production and then summed up.

3. Results and Discussion

To evaluate the estimates of the water consumption for cattle milk and meat production, the main results of the calculations using the WFP and WFPnet methods are reported in Table 2.

For meat production, total green water consumption considering the water used by rainfed crops showed a WFP equal to 3714 and 10371 L per kg of biomass for high and low efficiency scenarios, respectively. Total blue water consumption for forage irrigation varied from 3429 L to 4629 L per kg of meat for high and low feed efficiency, respectively. As reported in Table 2, water consumed in the feed production process, expressed as L per kg of carcass meat, depended on the amount of each type of feed used in the diet. Total water (blue + green) consumption for forage and grain production ranged from 8143 L to 18491 L per kg of meat for the high feed efficiency, high WUE scenario and the low feed efficiency, low WUE scenario, respectively. By summing up the total water consumption for forage and grain production and the drinking and servicing water, the calculated total WFP ranged from 8214 L to 18591 L per kg of meat for the high feed efficiency, high WUE scenario and the low feed efficiency, low WUE scenario, respectively (Table 2). These values are in agreement with the literature on the WFPN approach, with an average value of 15400 L of water to produce a kg of cattle meat in irrigated farms (Mekonen and Hoekstra, 2012; Table 1). From our findings, low feed efficiency conditions, associated with a low animal performance, led to a higher WFP compared with the high efficiency conditions, with +91%, +69% and +43% WFP for high, medium and low crop WUE scenarios, respectively.

When the water calculation considered the fact that the natural cover has a considerable water uptake for ET, which was subtracted from the agricultural water needs, a strong reduction in WFP was observed, as demonstrated by the values obtained with the WFPnet approach (Table 2). In fact, for the calculation of the net green water consumption, 100% of the yearly water consumption by natural woodland-shrubland was subtracted from the values of water consumption by the rainfed forages and grains, whereas only 15% of it was subtracted from the irrigated forages and grains, accounting for the summer evapotranspiration of the natural cover only (Katerji et al., 2008). In our study, the net green water use in rainfed areas allocated to livestock production was negative, in agreement with Nisbet (2005).

The total net water consumption for forages and grains ranged from 690 to 6929 L of water per kg of meat for the low feed efficiency, high crop WUE scenario and the high feed efficiency, low WUE scenario, respectively (Table 2). The total WFPnet, obtained by summing up total net water consumption for forages and grains and the drinking and services water, ranged from 790 to 7001 L of water per kg of meat for the low feed efficiency, high crop WUE scenario and the high feed efficiency, low WUE scenario, respectively (Table 2). Those values of water
consumption calculated with WFP$_{net}$ were equal to 5% and 54% of those obtained with the WFP calculation, respectively. As expected, the WFP$_{net}$ was higher for high feed efficiency scenarios, in which a large amount of feed from irrigated land was used in animal diets, than for low feed efficiency scenarios. The WFP$_{net}$ values for meat are closer to the values obtained by Capper and Bauman (2013), who calculated a 3600 kg of water consumption for very high performance systems of meat production considering an average crop WUE.

Table 2. Water footprint (WFP) and Net water footprint (WFP$_{net}$) for cattle milk and beef production in high and low feed efficiency systems with high, medium and low water use efficiency (WUE) scenarios.

<table>
<thead>
<tr>
<th></th>
<th>Meat</th>
<th>Milk</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>High Feed Efficiency</td>
<td>Low Feed Efficiency</td>
</tr>
<tr>
<td>Carcass weight, kg</td>
<td>350</td>
<td>250</td>
</tr>
<tr>
<td>Milk yield, kg/year per cow</td>
<td>9000</td>
<td>5500</td>
</tr>
<tr>
<td>Dry matter intake, kg/kg product</td>
<td>20</td>
<td>30</td>
</tr>
<tr>
<td>Drinking and service water consumption, L/kg product</td>
<td>71.4</td>
<td>100.0</td>
</tr>
<tr>
<td>Water consumed for forages and grains</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Using Scenario 1, high WUE: WFP, L/kg product</td>
<td>8143</td>
<td>15600</td>
</tr>
<tr>
<td>Using Scenario 2, medium WUE: WFP, L/kg product</td>
<td>9810</td>
<td>16600</td>
</tr>
<tr>
<td>Using Scenario 3, low WUE: WFP, L/kg product</td>
<td>12961</td>
<td>18491</td>
</tr>
<tr>
<td>Water consumed for forages and grains</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Using Scenario 1, high WUE: WFP$_{net}$, L/kg product</td>
<td>2230</td>
<td>690</td>
</tr>
<tr>
<td>Using Scenario 2, medium WUE: WFP$_{net}$, L/kg product</td>
<td>3880</td>
<td>1680</td>
</tr>
<tr>
<td>Using Scenario 3, low WUE: WFP$_{net}$, L/kg product</td>
<td>6929</td>
<td>3509</td>
</tr>
<tr>
<td>Final Water Footprint (WFP)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Using Scenario 1, high WUE: WFP, L/kg product</td>
<td>8214</td>
<td>15700</td>
</tr>
<tr>
<td>Using Scenario 2, medium WUE: WFP, L/kg product</td>
<td>9881</td>
<td>16700</td>
</tr>
<tr>
<td>Using Scenario 3, low WUE: WFP, L/kg product</td>
<td>13032</td>
<td>18591</td>
</tr>
<tr>
<td>Final Net Water Footprint (WFP$_{net}$)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Using Scenario 1, high WUE: WFP$_{net}$, L/kg product</td>
<td>2302</td>
<td>790</td>
</tr>
<tr>
<td>Using Scenario 2, medium WUE: WFP$_{net}$, L/kg product</td>
<td>3951</td>
<td>1780</td>
</tr>
<tr>
<td>Using Scenario 3, low WUE: WFP$_{net}$, L/kg product</td>
<td>7001</td>
<td>3609</td>
</tr>
</tbody>
</table>

1 L/kg: liters of water consumed per kg of animal product produced

For milk production, total water consumed for forages and grains, expressed as L of water per kg of milk, depended on the amount of each type of feed used in the diet, and ranged from 334 to 1109 L per kg of milk for the high feed efficiency, high crop WUE scenario and the low feed efficiency, low crop WUE, respectively (Table 2).

The total WFP, composed of the total water consumed in the feed production process and the drinking and services water, ranged from 341 to 1120 L per kg of milk for the high feed efficiency, high crop WUE scenario and the low feed efficiency, low crop WUE scenario, respectively (Table 2). Those values are in agreement with the values reported in literature using the WFN approach, with an average value of 1000 L of water to produce a kg of cattle milk in irrigated farms (Mekonen and Hoekstra, 2012; Table 1). From our findings, compared to the high feed efficiency scenario, low animal performance associated with low feed efficiency resulted in a higher WFP, which
was equal to +214%, +216% and +198% for high, medium and low crop WUE, respectively.

The WFP_{net} of total consumed water for milk production ranged from 26 to 408 L of water per kg of milk for the low feed efficiency, high crop WUE and the low feed efficiency, low WUE scenarios (Table 2). Those values of water consumption calculated with the WFP_{net} method were equal to 4% and 63% of those calculated with the WFP method, respectively. As expected, the WFP_{net} was higher for high feed efficiency scenarios compared with low feed efficiency scenarios because a large amount of feed from irrigated land is used in animal diets in the first case. From our results it appears that the production system with low feed efficiency had a lower WFP_{net} than the high feed efficiency scenario. This depended mainly on the larger use of rainfed land of the studied low feed efficiency livestock system, which is consistent with the typical livestock practices of the Mediterranean region, where a low amount of blue water is destined to livestock production.

4. Conclusions

Estimations of WFP and WFP_{net} carried out in this preliminary work highlight the differences between the two methods, with values of WFP being, on average, much higher than WFP_{net} values for both meat and milk. These differences confirm that the development of the WFP concept is still incomplete. The WFP_{net} method appears to be able to properly quantify the water consumption needed for animal food production, and we believe that the aspect of the green water source and destination should be updated. This work should stimulate discussions for further ecological considerations on the water balance in the planet and encourage a broad and detailed calculation to obtain values of WFP_{net} specifically measured on real farm conditions and territorial scale.

References


Water Footprint Network. 2015. www.waterfootprint.org