

The water footprint of soy milk and soy burger and equivalent animal products

A. Ertug Ercin^{a,*}, Maite M. Aldaya^b, Arjen Y. Hoekstra^a

^a Twente Water Centre, University of Twente, P.O. Box 217, 7500 AE Enschede, The Netherlands

^b United Nations Environment Programme, Division of Technology, Industry and Economics, Sustainable Consumption and Production Branch, 15, rue de Milan F-75441, Paris, France

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ABSTRACT

As all human water use is ultimately linked to final consumption, it is interesting to know the specific water consumption and pollution behind various consumer goods, particularly for goods that are water-intensive, such as foodstuffs. The objective of this study is to quantify the water footprints of soy milk and soy burger and compare them with the water footprints of equivalent animal products (cow's milk and beef burger). The study focuses on the assessment of the water footprint of soy milk produced in a specific factory in Belgium and soy burger produced in another factory in the Netherlands. The ingredients used in the products are same as real products and taken from real case studies. We analysed organic and non-organic soybean farms in three different countries from where the soybeans are imported (Canada, China, and France). Organic production reduces soil evaporation and diminishes the grey water footprint, ultimately reducing the total water footprint. The water footprint of 1 l soy milk is 297 l, of which 99.7% refers to the supply chain. The water footprint of a 150 g soy burger is 158 l, of which 99.9% refers to the supply chain. Although most companies focus on just their own operational performance, this study shows that it is important to consider the complete supply chain. The major part of the total water footprint stems from ingredients that are based on agricultural products. In the case of soy milk, 62% of the total water footprint is due to the soybean content in the product; in the case of soy burger, this is 74%. Thus, a detailed assessment of soybean cultivation is essential to understand the claim that each product makes on freshwater resources. This study shows that shifting from non-organic to organic farming can reduce the grey water footprint related to soybean cultivation by 98%. Cow's milk and beef burger have much larger water footprints than their soy equivalents. The global average water footprint of a 150 g beef burger is 2350 l and the water footprint of 1 l of cow's milk is 1050 l.

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1. Introduction

Given that severe freshwater scarcity is a common phenomenon in many regions of the world, improving the governance of the world's limited annual freshwater supply is a major challenge, not only relevant to water users and managers but also to final consumers, businesses and policymakers in a more general sense (UNESCO, 2006). About 86% of all water used in the world is to grow food (Hoekstra and Chapagain, 2008). Therefore, food choices can have a big impact on water demand (Steinfeld et al., 2006; De Fraiture et al., 2007; Peden et al., 2007; Galloway et al., 2007). In industrialized countries, an average meat-eater consumes the equivalent of about 3600 l of water a day, which is 1.6 times more than the 2300 l used daily by people on vegetarian diets (assuming the vegetarians still consume dairy products; Hoekstra, 2010).

Fresh water is a basic ingredient in the operations and supply chains of many companies. A company may face multiple risks related to failure in properly managing freshwater supplies: damage to its corporate image, the threat of increased regulatory control, financial risks caused by pollution, and inadequate freshwater availability for business operations (Rondinelli and Berry, 2000; Pegram et al., 2009). The need for the food industry to take a responsible approach towards the sustainable use and conservation of fresh water is therefore vital.

The 'water footprint' is an indicator of water use that looks at both direct and indirect water use by a consumer or producer (Hoekstra, 2003). The water footprint is a comprehensive indicator of freshwater resources appropriation, which goes beyond traditional restrictive measures of water withdrawal. The water footprint of a product is defined as the total volume of fresh water that is used directly or indirectly to produce the product. It is estimated by considering water consumption and pollution in all steps of the production chain (Hoekstra et al., 2011). The blue water footprint refers to consumption of blue water resources (surface and ground water) along the supply chain of a product. 'Consumption' refers to the loss of water from the available ground and surface

* Corresponding author. Tel.: +31 534854466; fax: +31 534855377.

E-mail addresses: a.e.ercin@ctw.utwente.nl (A.E. Ercin), Maite.Aldaya@unep.org (M.M. Aldaya), a.y.hoekstra@utwente.nl (A.Y. Hoekstra).

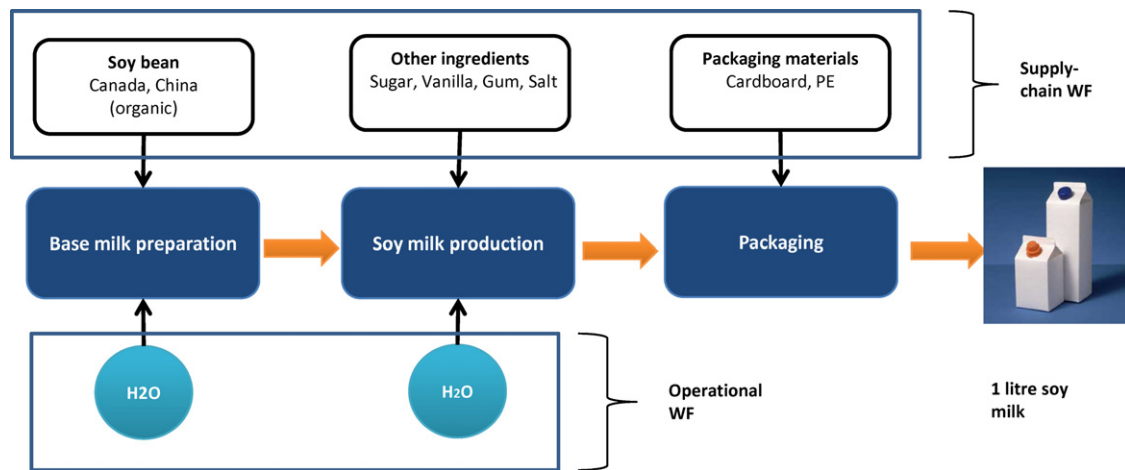


Fig. 1. Production-chain diagram of soy milk produced in Belgium.

water in a given catchment area. It includes evaporatranspiration, water incorporated into products and return waters to another catchment area or the sea. The green water footprint refers to consumption of green water resources (rainwater). The grey water footprint refers to pollution and is defined as the volume of freshwater that is required to assimilate the load of pollutants based on existing ambient water quality standards.

This paper analyses the water footprints of soy milk and soy burger and compares them with the water footprints of two equivalent animal products (cow's milk and beef burger). For this purpose, we first identified the production-chain diagram of 1 l of soy milk and of 150 g soy burger. We also indicated the relevant process steps with substantial water footprints. The study focuses on the assessment of the water footprint of soy milk produced in a specific factory in Belgium and soy burger produced in a specific factory in the Netherlands. The soybeans used in the manufacturing of the soy products in these two countries are imported. The study starts with the assessment of the water footprint of soybean cultivation in Canada, China and France, three of the actual source countries, differentiating between the green, blue and grey water footprint components. Different types of soybean production systems are analysed: organic versus non-organic and irrigated versus rain-fed. Next, the water footprint of each of the final products is assessed based on the composition of the product and the characteristics of the production process and producing facility. Finally, we compare the water footprints of soy products with the water footprints of equivalent animal products.

2. Method and data

In order to estimate the water footprint of soy milk and soy burger, first we identified production systems. A production system consists of sequential process steps. Figs. 1 and 2 show the production system of soy milk and soy burger, respectively. These production diagrams show only the major process steps during the production and the inputs for each step that are most relevant for water footprint accounting. They do not show other steps in the life cycle of the products like transportation, elevation, distribution, end-use and disposal.

Taking the perspective of the producer of the soy milk and soy burger, the water footprints of the soy products include an operational and a supply-chain water footprint. The operational (or direct) water footprint is the volume of freshwater consumed or polluted in the operations of the producer of the soy products. It refers to the fresh water appropriated during the production of the soy products from their basic ingredients: water incorporated into the products, water evaporated during production processes and the volume of water polluted because of wastewater leaving the factory. The supply-chain (or indirect) water footprint is the volume of freshwater consumed or polluted to produce all the goods and services that form the input of production of the business. Both operational and supply-chain water footprints consist of two parts: the water footprint that can be directly related to inputs needed in or for the production of the product and an overhead water footprint. The overhead water footprint refers to freshwater use

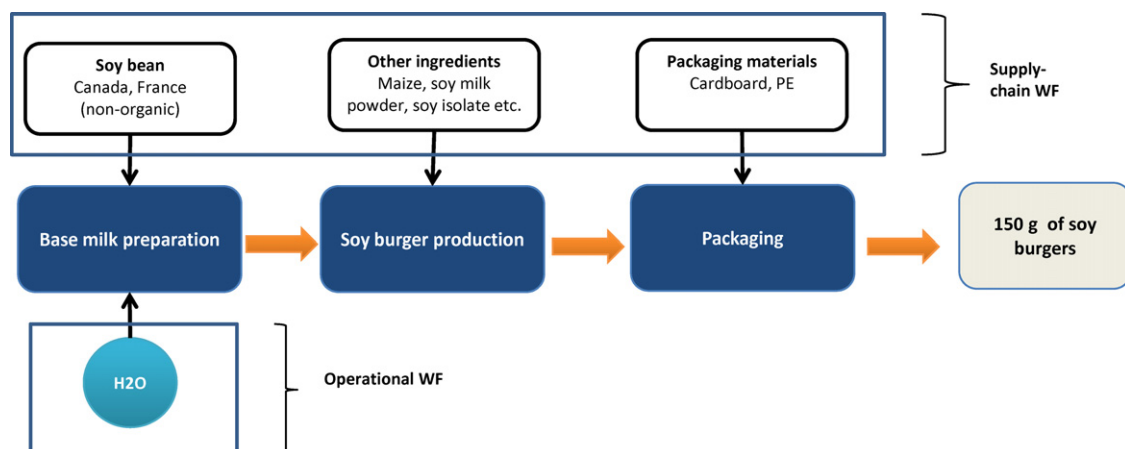


Fig. 2. Production-chain diagram of a 150 g soy burger produced in the Netherlands.

that in first instance cannot be fully associated with the production of the specific product considered, but refers to freshwater use that associates with supporting activities and materials used in the business, which produces not just this specific product but other products as well. The overhead components of the operational and supply-chain water footprints are excluded from this study as they are negligible compared to the total water footprint for food-based products (Ercin et al., 2011). Additionally, the water footprint related to transport of materials and energy used during production are excluded from this study as they are negligible compared to the total water footprint for food-based products (Ercin et al., 2011).

The supply-chain water footprint is composed of the water footprints of ingredients (e.g. soybean, sugar, maize, and natural flavouring in the case of soy milk and soybean, maize, onion, paprika, carrots for soy burger) and the water footprints of other components (e.g. bottle, cap, labelling materials, packaging materials). The list of ingredients and amounts used in the soy products are taken from real case studies (Tables 1 and 2). For the soy milk, the soybean is supplied from two different farms that cultivate organic soybean: a rainfed farm located in China and a rainfed farm located in Canada. In the production stage of the soy milk, a mix of soybeans from these two farms is used, according to a ratio of 50–50. For the soy burger, soybean is supplied from three non-organic farms: a rainfed farm located in Canada, a rainfed farm located in France, and an irrigated farm in the same region in France. A mix of soybeans from these farms is used in the soy burger, according to a ratio of 50/25/25.

The water footprints of different ingredients and other inputs are calculated distinguishing between the green, blue and grey water footprint components. The water footprint definitions and calculation methods applied follow Hoekstra et al. (2011). In order to calculate the water footprint of the soy products, we first calculated the water footprints of the original materials (raw materials) of the ingredients. The water footprint of agricultural raw materials (crops) is calculated as follows:

The green and blue component in water footprint of crops ($WF_{\text{green/blue}}$, m^3/ton) is calculated as the green and blue components in crop water use ($CWU_{\text{green/blue}}$, m^3/ha) divided by the crop yield (Y , ton/ha).

$$WF_{\text{green/blue}} = \frac{CWU_{\text{green/blue}}}{Y} \quad (1)$$

The green and blue water crop water use were calculated using the CROPWAT model (Allen et al., 1998; FAO, 2009a). Within the CROPWAT model, the 'irrigation schedule option' was applied, which includes dynamic soil water balance and tracks the soil moisture content over time (Allen et al., 1998). The calculations were done using climate data from the nearest and most representative meteorological stations and a specific cropping pattern for each crop according to the type of climate. Monthly values of major climatic parameters were obtained from the CLIMWAT database (FAO, 2009b). Crop area data were taken from Monfreda et al. (2008); crop parameters (crop coefficients, planting date and harvesting date) were taken from Allen et al. (1998) and FAO (2009a). Types of soil and average crop yield data were obtained from the farms (Table 3). Soil information was taken from FAO (2009a). All collected data are used as inputs for the CROPWAT model for calculation of crop water use.

In the case of the Chinese organic soybean production, organic compost mixed with the straw of the crop and the waste of livestock was applied. 50% of the soil surface was assumed to be covered by the organic crop residue mulch, with the soil evaporation being reduced by about 25% (Allen et al., 1998). For the crop coefficients in the different growth stages this means: K_c,ini , which represents mostly evaporation from soil, is reduced by about 25%; K_c,mid is

Table 1
Water footprints of raw materials and process water footprints for the ingredients and other components of 1 l soy milk.

| Ingredients | Raw material | Amount ^e | Source | Water footprint of raw material (m^3/ton) ^b | | | Process water footprint (m^3/ton) ^b | | | Fractions for products used ^a | |
|----------------------|--------------|---------------------|----------------------------------|--|------|------|--|------|------|--|----------------|
| | | | | Green | Blue | Grey | Green | Blue | Grey | Product fraction | Value fraction |
| | | | | | | | | | | | |
| Soybean ^c | Soybean | 70 | Canada + China (organic) | 1753.5 | 0 | 18.5 | 0 | 0 | 0 | 0.64 | 0.95 |
| Cane sugar | Sugar cane | 25 | Cuba | 358 | 50 | 2 | 0 | 0 | 0 | 0.11 | 0.87 |
| Maize starch | Maize | 0.30 | China | 565 | 12 | 335 | 0 | 0 | 0 | 0.75 | 1 |
| Vanilla flavour | Vanilla | 0.15 | USA | 67269 | 7790 | 0 | 0 | 0 | 0 | 9 ^d | 1 |
| Other components | | | | | | | | | | | |
| Cardboard | Wood | 25 | Germany | 616 | 0 | 0 | 0 | 0 | 180 | 1 | 1 |
| Cap | Oil | 2 | Sweden (raw) – Germany (process) | 0 | 0 | 10 | 0 | 0 | 225 | 1 | 1 |
| Tray – cardboard | Wood | 10 | Germany | 616 | 0 | 0 | 0 | 0 | 180 | 1 | 1 |
| Stretch film (LDPE) | Oil | 1.5 | Sweden (raw) – Germany (process) | 0 | 0 | 10 | 0 | 0 | 225 | 1 | 1 |

^a Mekonnen and Hoekstra (2010a) and Van Oel and Hoekstra (2010) for wood.

^b Van der Leeden et al. (1990).

^c Data for soybean: own calculations.

^d FDA (2006).

^e Total weight of ingredients is 0.1 kg. The rest of the weight is water, which is added in the operational phase.

Table 2
Water footprints of raw materials and process water footprints for the ingredients and other components of 150 g soy burger.

| 150 g of soy burger | Raw material | Amount ^d | Source | Water footprint of raw material (m ³ /ton) ^a | | | Process water footprint (m ³ /ton) ^b | | | Fractions for products used ^a | |
|---|---------------|---------------------|----------------------------------|--|------|------|--|------|------|--|----------------|
| | | | | Green | Blue | Grey | Green | Blue | Grey | Product fraction | Value fraction |
| Ingredients | | | | | | | | | | | |
| Soybean ^c | Soybean | 25 | France + Canada (non-organic) | 1860 | 130 | 795 | 0 | 0 | 0 | 0.64 | 0.95 |
| Maize | Maize | 4 | Turkey | 646 | 208 | 277 | 0 | 0 | 0 | 1 | 1 |
| Soy milk powder | Soybean | 4 | USA | 1560 | 92 | 10 | 0 | 0 | 0 | 0.57 | 1 |
| Soya paste | Soybean | 4 | USA | 1560 | 92 | 10 | 0 | 0 | 0 | 3.75 | 1 |
| Onions | Onions | 4 | Nether-lands | 68 | 5 | 18 | 0 | 0 | 0 | 1 | 1 |
| Paprika green | Peppers green | 5 | Spain | 39 | 3 | 37 | 0 | 0 | 0 | 1 | 1 |
| Carrots | Carrots | 2 | Nether-lands | 57 | 3 | 18 | 0 | 0 | 0 | 1 | 1 |
| Other components | | | | | | | | | | | |
| Sleeve (cardboard) | Wood | 15 | Germany | 616 | 0 | 0 | 0 | 0 | 180 | 1 | 1 |
| Plastic cup | Oil | 15 | Sweden (raw) – Germany (process) | 0 | 0 | 10 | 0 | 0 | 225 | 1 | 1 |
| Cardboard box (contains 6 burger packs) | Wood | 25 | Germany | 616 | 0 | 0 | 0 | 0 | 180 | 1 | 1 |
| Stretch film (LDPE) | Oil | 0.5 | Sweden (raw) – Germany (process) | 0 | 0 | 10 | 0 | 0 | 225 | 1 | 1 |

^a Mekonnen and Hoekstra (2010a) and Van Oel and Hoekstra (2010) for wood.

^b Van der Leeden et al. (1990).

^c Data for soybean: own calculations.

^d Total weight of ingredients is 0.05 kg. The rest of the weight is water, which is added in the operational phase.

Table 3
Planting and harvesting dates, yield and type of soil for the five soybean farms considered.

| Crop | Planting date ^a | Harvesting date ^a | Yield (ton/ha) ^a | Type of soil |
|------------------------------|----------------------------|------------------------------|-----------------------------|------------------------|
| Canada organic rainfed | 15 May | 11 October | 2.4 | Sandy loam – Clay loam |
| Canada non-organic rainfed | 15 May | 11 October | 2.5 | Clay loam |
| China organic rainfed | 15 May | 11 October | 2.9 | Brown soil |
| France non-organic rainfed | 15 May | 11 October | 1.9 | Calcareous clay |
| France non-organic irrigated | 15 May | 11 October | 3.1 | Calcareous clay |

^a Farm data.

reduced by 25% of the difference between the single crop coefficient ($K_{c,mid}$) and the basal crop coefficient ($K_{cb,mid}$); and $K_{c,end}$ is similarly reduced by 25% of the difference between the single crop coefficient ($K_{c,end}$) and the basal crop coefficient ($K_{cb,end}$). Generally, the differences between the K_c and K_{cb} values are only 5–10%, so that the adjustment to $K_{c,mid}$ and $K_{c,end}$ to account for organic mulch may not be very large.

The grey water footprint of crops is calculated by dividing the pollutant load (L , in mass/time) by the difference between the ambient water quality standard for that pollutant (the maximum acceptable concentration c_{max} , in mass/volume) and its natural concentration in the receiving water body (c_{nat} , in mass/volume).

$$WF_{proc, grey} = \frac{L}{c_{max} - c_{nat}} \quad (2)$$

Generally, soybean production leads to more than one form of pollution. The grey water footprint was estimated separately for each pollutant and finally determined by the pollutant that appeared to be most critical, i.e. the one that is associated with the largest pollutant-specific grey water footprint (if there is enough water to assimilate this pollutant, all other pollutants have been assimilated as well). The total volume of water required per ton of pollutant was calculated by considering the volume of pollutant leached (ton/ton) and the maximum allowable concentration in the ambient water system. The natural concentration of pollutants in the receiving water body was assumed to be negligible. Pollutant-specific leaching fractions and ambient water quality standards were taken from the literature (Table 4). In the case of phosphorus, good estimates on the fractions that reach the water bodies by leaching or runoff are very difficult to obtain. The problem for a substance like phosphorus (P) is that it partly accumulates in the soil, so that not all P that is not taken up by the plant immediately reaches the groundwater, but on the other hand may do so later. In this study we assumed a P leaching rate of zero.

Second step in calculation of water footprints of the soy products is the calculation of water footprints of each ingredient of the soy products. The water footprint of ingredient (p) is calculated as:

$$WF_{prod}[p] = (WF_{proc}[p] + \frac{WF_{prod}[i]}{f_p[p, i]}) \times f_v[p] \quad (3)$$

in which $WF_{prod}[p]$ is the water footprint of ingredient, $WF_{prod}[i]$ is the water footprint of raw material i and $WF_{proc}[p]$ the process water footprint. Parameter $f_p[p, i]$ is the 'product fraction' and parameter $f_v[p]$ is the 'value fraction'. The product fraction of ingredient p that is processed from raw material i ($f_p[p, i]$, mass/mass) is defined as the quantity of the ingredient ($w[p]$, mass) obtained per quantity of raw material ($w[i]$, mass):

$$f_p[p, i] = \frac{w[p]}{w[i]} \quad (4)$$

The value fraction of ingredient p ($f_v[p]$, monetary unit/monetary unit) is defined as the ratio of the market value of this ingredient

to the aggregated market value of all the outputs products ($p = 1$ to z) obtained from the raw material:

$$f_v[p] = \frac{price[p] \times w[p]}{\sum_{p=1}^z (price[p] \times w[p])} \quad (5)$$

The water footprint of the soy products is then sum of water footprint of all ingredients ($p = 1$ to y) multiplied with the amounts of ingredients (M_p) used in the products:

$$WF_{soyproducts} = \sum_{p=1}^y WF_p \times M_p \quad (6)$$

As an example to water footprint calculation of the ingredients, we show here the case of soybean used in 150 g of soy burger. The amount of soybean used in the soy burger is 0.025 kg and is cultivated in Canada and France (50% each). The green, blue and grey water footprints of the soybean mix are 1860, 130 and 795 m³/ton, respectively. About 86% of the weight of soybean becomes dehulled soybean (DS) and about 74% of the DS weight becomes base milk. The product fraction for soybean in the product (basemilk) is thus $0.86 \times 0.74 = 0.64$. In the process from soybean to basemilk, there are also by-products with some value. The value of the basemilk is 94% of the aggregated value of soybean products. Therefore, 94% of the water footprint of the soybean is attributed to basemilk. The water footprint of the basemilk as used in the soy milk is calculated by multiplying the water footprint of soybean by the value fraction and amount used and dividing by the product fraction. The green water footprint of the basemilk is thus: $(1860 \times 0.94 \times 0.025)/0.64 = 69.11$. The blue water footprint: $(130 \times 0.94 \times 0.025)/0.64 = 4.81$. The grey water footprint: $(795 \times 0.94 \times 0.025)/0.64 = 29.51$.

For the other agricultural ingredients, water footprints of raw products, product fractions and value fractions have been taken from Mekonnen and Hoekstra (2010a). We calculated the product and value fractions of the vanilla extract according to the extracting process defined as in FDA (2006). In this calculation, we assumed that single fold vanilla extract is used in the soy milk. The water footprints of raw materials, process water footprints, product fractions and value fractions, on which the soy milk and soy burger water footprint's calculation is based, are given in Tables 1 and 2.

The supply-chain water footprint of soy products is not only caused by ingredients but also other components integral to the whole product. These include closure, labelling and packaging materials. The process water footprints and the water footprints associated with other raw materials used (oil, PE, LDPE, and PP) have been derived from Van der Leeden et al. (1990). The detailed list of other components of the supply-chain water footprint of the product is given in Tables 1 and 2. The water footprints of raw materials, process water footprints, product fractions and value fraction are presented in Tables 1 and 2.

Data related to the operational water footprint of soy milk and soy burger are taken from two real factories in Belgium and the Netherlands. Both factories have treatment plants that treat the wastewater before discharging it into the receiving water bodies. All wastewater leaving the factories is treated with 100% treatment

Table 4
Fertilizer and pesticide application and leaching rate and ambient water quality standards..

| Type of agriculture | Chemical | Active substance | Application rate (kg/ha) | Leaching rate (%) | Leaching rate source | Standard (mg/l) | Standard source |
|---------------------|-------------------------------------|---------------------|--------------------------|-------------------|-------------------------------|-----------------|---|
| Organic | Sulphate of potash | Sulphate | 25 | 60 | Eriksen and Askegaard (2000) | 300 | MDEQ(1996) in MacDonald et al. (1999) |
| | Rock phosphate | Phosphorus | 11 | 0 | | | |
| | Organic compost | Nitrogen | 1 | 10 | Hoekstra and Chapagain (2008) | 10 | EPA (2010) |
| Non-organic | Potassium chloride | Chloride | 20 | 85 | Stites and Kraft (2001) | 860 | EPA (2010) CMC – Criteria Maximum Concentration |
| | TSP | Phosphorus | 24 | 0 | | | |
| | Touchdown | Glyphosate | 1 | 0.01 | Doussset et al. (2004) | 0.065 | MDEQ(1996) in MacDonald et al. (1999) |
| | Boundary | Metolachlor | 2.4 | 1 | Singh (2003) | 0.008 | MDEQ(1996) in MacDonald et al. (1999) |
| | Boundary | Metribuzin | 2.4 | 0 | Kjaer et al. (2005) | 0.001 | MDEQ(1996) in MacDonald et al. (1999) |
| | P ₂ O ₅ Lasso | Phosphorus Alachlor | 33 2 | 0 2.5 | Persicani et al. (1995) | 0.048 | MDEQ(1996) in MacDonald et al. (1999) |

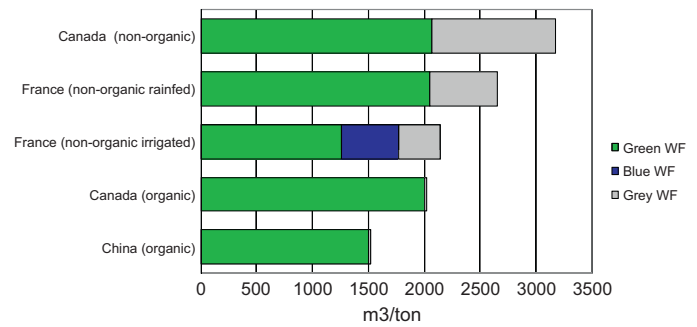


Fig. 3. The water footprint of soybeans (as primary crops) from different farms (m³/ton).

performance at both treatment plants and effluent characteristics of the treated wastewater are below the legal limits. Therefore, we took the grey water footprint as zero by assuming that the concentration of the pollutant in the effluent is equal to its actual concentration in the receiving water body.

The water used as an ingredient is equal to 0.1 l per 150 g of soy burger and 0.9 l per 1 l of soy milk. The production of soy milk and soy burger includes the following process steps: base milk preparation, mixing, filling, labelling and packaging. The water balance recordings of the factories showed that the amount of water lost (evaporated) is zero during all these processes. Base milk in the production process refers to the preparation of concentrated milk.

The water footprints of cow's milk and beef depend on the water footprints of the feed ingredients consumed by the animal during its lifetime and the water footprints related to drinking and service water (Hoekstra and Chapagain, 2008). Clearly, one needs to know the age of the animal when slaughtered and the diet of the animal during the various stages of its life. The water footprints of cow's milk and beef burger have been taken from Mekonnen and Hoekstra (2010b). For the comparison with the soy products, the water footprint of packaging is included in the water footprints of cow's milk and beef burger as well.

3. Results

3.1. Water footprint of soybean

The water footprints of soybean cultivated in five different farms located in three different countries are shown in Fig. 3. The soybean from the Canadian non-organic farm has the largest water footprint, followed by the two French non-organic farms, the Canadian organic farm and Chinese organic farm. The blue water footprint component is zero except for the soybean from the French irrigated farm. The soybean from the rest of the farms is rainfed. The largest grey water footprint is found for the soybean from the Canadian non-organic farm.

3.1.1. Soybean cultivation in Canada

In Canada, two different plantations were analysed: a rainfed organic and a rainfed non-organic soybean farm. As reported in Table 3, crop yields for the organic and non-organic soybean production in the Canadian farms are similar (2.4 and 2.5 ton/ha, respectively). The water footprint of non-organic soybean production is about 3172 m³/ton (2069 m³/ton green and 1103 m³/ton grey) (Fig. 3). The grey water footprint is determined by Boundary herbicide, which has the largest pollutant-specific grey water footprint (1103 m³/ton), followed by potassium chloride (8 m³/ton), Touchdown (1 m³/ton) and TSP (0 m³/ton). The total water footprint of organic soybean production in the Canadian farm is around 2024 m³/ton (2004 m³/ton green, 20 m³/ton grey). In this case, the

Table 5
The water footprint of 1 l of soy milk.

| | Water footprint (l) | | | | % in total |
|--------------------------------------|---------------------|------|------|-------|------------|
| | Green | Blue | Grey | Total | |
| Water incorporated into the soy milk | 0 | 0.9 | 0 | 0.9 | 0.3 |
| Water consumed during process | 0 | 0 | 0 | 0 | 0 |
| Wastewater discharge | 0 | 0 | 0 | 0 | 0 |
| Operational water footprint | 0 | 0.9 | 0 | 0.9 | 0.3 |
| Soybean (basemilk) | 182.3 | 0 | 1.9 | 184.2 | 62 |
| Cane sugar | 71.1 | 9.9 | 0.4 | 81.5 | 27.5 |
| Maize starch | 0.2 | 0 | 0.1 | 0.4 | 0.1 |
| Vanilla flavour | 1.1 | 0.1 | 0 | 1.3 | 0.4 |
| Ingredients total | 254.7 | 10 | 2.4 | 267.4 | 90 |
| Cardboard | 15.4 | 0.0 | 4.5 | 19.9 | 6.7 |
| Cap | 0.0 | 0.0 | 0.5 | 0.5 | 0.2 |
| Tray – cardboard | 6.2 | 0.0 | 1.8 | 8.0 | 2.7 |
| Stretch film (LDPE) | 0.0 | 0.0 | 0.4 | 0.4 | 0.1 |
| Other components total | 21.6 | 0 | 7.2 | 28.8 | 9.7 |
| Supply-chain water footprint | 276.4 | 10.1 | 9.6 | 296 | 99.7 |
| Total | 276.4 | 11.0 | 9.6 | 296.9 | |

sulphate of potash is the most critical pollutant (20 m³/ton). The nitrogen fertilization through symbiotic and endophytic bacteria as applied in organic farming has a zero grey water footprint.

3.1.2. Soybean cultivation in China

The Chinese organic rainfed farm under study achieves high yields, amounting to about 2.9 ton/ha, notably higher than the Chinese national average (1.7 ton/ha). The total water footprint of the Chinese organic rainfed soybean production is 1520 m³/ton (1503 m³/ton green and 17 m³/ton grey). The grey water footprint is related to the sulphate pollution coming from the sulphate of potash applied. The grey water footprint of nitrogen due to organic compost is 4 m³/ton and the one of phosphorus (P₂O₅) is negligible. In this case, organic compost mixed by the straw of the crop and the waste of the livestock is applied, mainly before planting.

3.1.3. Soybean cultivation in France

The non-organic rainfed French farm studied has a low yield of around 1.9 ton/ha, whereas the irrigated one gives 3.1 ton/ha, higher than the national average (2.5 ton/ha). The water footprint of the soybean from the rainfed farm is calculated as 2651 m³/ton (2048 m³/ton green and 603 m³/ton grey). The water footprint for the irrigated farm is estimated as 2145 m³/ton (1255 m³/ton green, 519 m³/ton blue and 370 m³/ton grey). In both cases, the grey water footprint is determined by the Lasso pesticide (alachlor) applied (603 and 370 m³/ton for rainfed and irrigated production, respectively), followed by the potassium chloride pollution (10 and 6 m³/ton respectively) and TSP (0 m³/ton).

3.2. Water footprint of soy products

The operational water footprints of soy milk and soy burger are very small (Tables 5 and 6). Both green and grey water footprints are zero. The blue water footprint is 0.9 l for soy milk and 0.1 l for soy burger. The total operational water footprint is thus no more than the water used as ingredient of the products.

The water footprints of the two soy products are largely determined by the supply chain components. About 62% of the total water footprint of soy milk refers to the water footprint of soybean cultivation. In the case of soy burger, this is 65%. In the case of soy milk, 90% of the supply-chain water footprint is from ingredients (mainly soybean and cane sugar) and 10% is from other components (mainly cardboard). For soy burger, the percentages are 78% and 22% respectively.

The results in Tables 5 and 6 are calculated based on the figures given in Tables 1 and 2. As an example, we show here the calculation of the water footprint of soybean used in 150 g of soy burger. The amount of soybean used in the soy burger is 0.025 kg and is cultivated in Canada and France (50% each). All soybeans come from non-organic farms. In France, the soybean come partly from rainfed lands and partly from irrigated lands. The Canadian soybean is taken from rainfed fields. The water footprints of soybeans as primary crop from different locations are given in Table 7. The green, blue and grey water footprints of soybean from Canada are 2069, 0 and 1103 m³/ton, respectively. For rainfed soybean from France this is 2048, 0, and 603 m³/ton, respectively. For irrigated French soybean, we find values of 1255, 519 and 370 m³/ton. Based on relative amounts per source, we can calculate that the green, blue and grey water footprints of the resulting soybean mix are 1860, 130 and 795 m³/ton, respectively.

The total water footprints of 1 l of soy milk and 150 g of soy burger are calculated as 297 and 158 l respectively. For soy milk, 99.7% of total water footprint stems from the supply-chain water footprint. For soy burger this is 99.9%. This highlights the importance of detailed supply chain assessments for both products and businesses. Common practice in business water accounting is the focus on the operational water consumption. However, this study shows that compared to the supply-chain water footprint, the operational side is almost negligible. The diagrams in Fig. 4 show the colour composition of the water footprints of soy milk and soy burger. 93% of the total water footprint of the 1 l of soy milk is from green water resources, 4% is from blue water resources and 3% is the grey water footprint component. The colours of the water

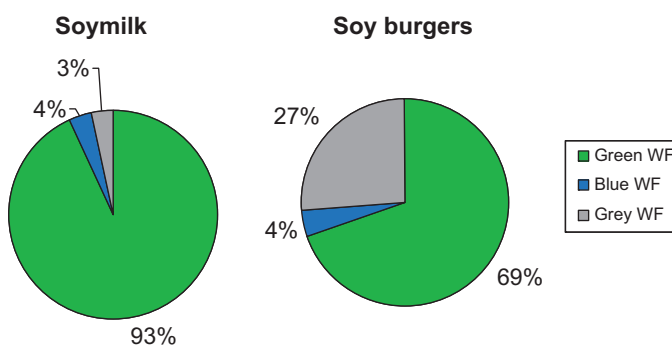


Fig. 4. The green, blue and grey shares in the total water footprints of 1 l soy milk and 150 g soy burger.

Table 6
The water footprint of 150 g of soy burger.

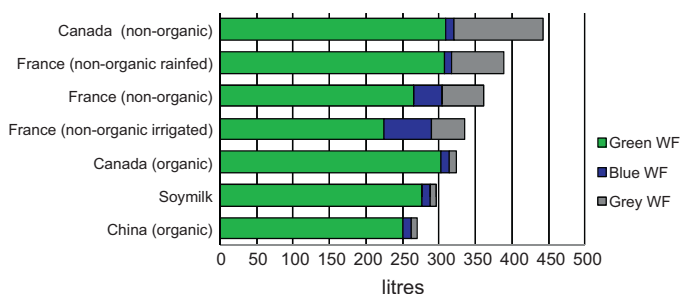
| | Water footprint (l) | | | | % in total |
|---|---------------------|------|------|-------|------------|
| | Green | Blue | Grey | Total | |
| Water incorporated into the soy milk | 0 | 0.1 | 0 | 0.1 | 0.06 |
| Water consumed during process | 0 | 0 | 0 | 0 | 0 |
| Wastewater discharge | 0 | 0 | 0 | 0 | 0 |
| Operational water footprint | 0 | 0.1 | 0 | 0.1 | 0.06 |
| Soybean (basemilk) | 69.1 | 4.8 | 29.5 | 103.4 | 65.5 |
| Maize | 2.6 | 0.8 | 1.1 | 4.5 | 2.8 |
| Soy milk powder | 10.9 | 0.6 | 0.1 | 11.7 | 7.4 |
| Soya paste | 1.7 | 0.1 | 0.0 | 1.8 | 1.1 |
| Onions | 0.3 | 0 | 0.1 | 0.4 | 0.3 |
| Paprika green | 0.2 | 0 | 0.2 | 0.4 | 0.3 |
| Carrots | 0.1 | 0 | 0 | 0.2 | 0.1 |
| Ingredients total | 84.9 | 6.3 | 31 | 122.4 | 77.5 |
| Sleeve (cardboard) | 9.2 | 0 | 2.7 | 11.9 | 7.5 |
| Plastic cup | 0.0 | 0 | 3.5 | 3.5 | 2.2 |
| Cardboard box (contains 6 burger packs) | 15.4 | 0 | 4.5 | 19.9 | 12.6 |
| Stretch film (LDPE) | 0 | 0 | 0.1 | 0.1 | 0.06 |
| Other components total | 24.6 | 0 | 10.8 | 35.4 | 22.36 |
| Supply-chain water footprint | 109.5 | 6.4 | 41.8 | 157.8 | 99.9 |
| Total | 109.5 | 6.5 | 41.8 | 157.9 | |

Table 7
Summary of the water footprints of soybeans as primary crop (as input to a soy burger).

| Farm | Water footprint (m ³ /ton) | | | | Percentage in mix |
|---------------------------------|---------------------------------------|------|------|-------|-------------------|
| | Green | Blue | Grey | Total | |
| Canada (non-organic, rainfed) | 2069 | 0 | 1103 | 3172 | 50 |
| France (non-organic, rainfed) | 2048 | 0 | 603 | 2651 | 25 |
| France (non-organic, irrigated) | 1255 | 519 | 370 | 2145 | 25 |
| Soybean mix (for soy burger) | 1860 | 130 | 795 | 1860 | |

footprint of 150 g soy burger are 69% green, 4% blue and 27% the grey.

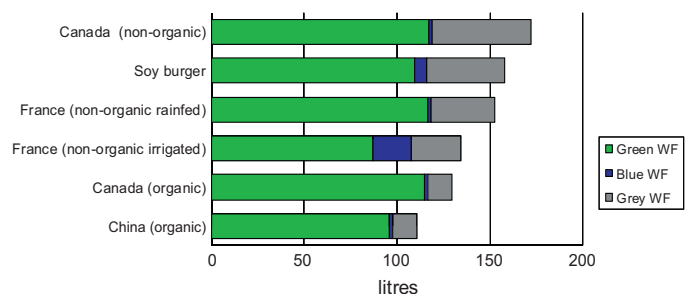
The water footprints of soy milk and soy burger from the Belgian and Dutch factories are calculated based on the percentages of soybean intake from different farms. Fig. 5 shows the change in the total footprint of 1 l of soy milk according to farm location and type of agricultural practice (organic versus non-organic and rainfed versus irrigated). The soybean used as an ingredient in the ‘soy milk product’ is supplied from both Canadian and Chinese organic farms (50% each). Fig. 5 shows the total water footprint values of the same product when soybeans are fully supplied from either the Canadian organic, Chinese organic, French non-organic rainfed, French non-organic irrigated, or Canadian non-organic farm. If the soybean were only supplied from the Canadian non-organic farm, the water footprint of 1 l of soy milk would be 49% larger. If all soybeans were supplied from the Chinese organic farm, then the water footprint of the soy milk product would be 9% smaller. Shifting from full non-organic (as in the one Canadian farm) to full organic (as in the other Canadian farm) reduces the grey water footprint related to soybean cultivation by 98%.

**Fig. 5.** The total water footprint of soy milk with soybean input from different farms (l).

The soybean in the 150 g of soy burger is supplied from three different farms: a non-organic Canadian farm (supplying 50% of the soybean) and two non-organic French farms, a rainfed one and an irrigated one (both supplying 25%). The total water footprint of this soy burger is 158 l (Fig. 6). If we were to source soybean only from the Canadian non-organic farm, the total water footprint of our product would be 9% higher. However, if we sourced soybean from the Chinese organic farm that we studied for the soy milk case, the total water footprint of our soy burger would decrease by 30%.

3.3. Water footprint of soy products versus equivalent animal products

The water footprints of cow's milk and beef burger have been studied in detail before by Chapagain and Hoekstra (2004) and recently by Mekonnen and Hoekstra (2010b). In this study we make use of the estimates from the latter study. In the latter study packaging is not included in the water footprint values. Therefore, for the comparison of cow's milk and soy milk, the water footprint of packaging material is added to the water footprint of cow's milk (27.8 l

**Fig. 6.** The total water footprint of soy burger with soybean input from different farms (l).

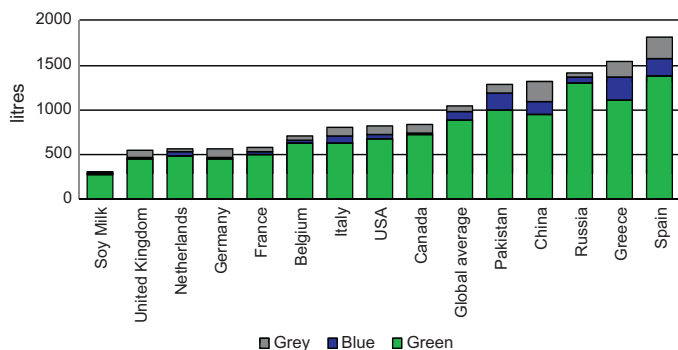


Fig. 7. The water footprint of 1 l of soy milk compared to the water footprint of 1 l of cow's milk from various locations (in l).

per 1 l of milk). Similarly, the water footprint of packaging materials is added to the beef burger for fair comparison with the soy burger (35.5 l per 150 g of beef burger). The packing for animal products are taken as same as the soybean products.

Fig. 7 shows the water footprint of 1 l of soy milk produced in Belgium in comparison to the water footprint of 1 l of cow's milk from various locations. The smallest water footprint of cow's milk is 540 l for the UK and the largest is 1800 l for Spain, while the world average amounts to 1050 l.

Fig. 8 compares the water footprint of 150 g of soy burger produced in the Netherlands with the water footprints of beef burgers from different locations. As seen in the figure, soy burger has a smaller water footprint (158 l) than all the beef burgers from any source. The largest water footprint of beef burger is from Pakistan (3650 l) and the lowest is from the Netherlands (1000 l), while the world average is 2350 l.

The water footprint values change by location as the climatic, soil conditions and production systems varies across the countries.

4. Discussions

The calculations in this study are based on some assumptions. First, we assumed that the concentration of the pollutant in the effluent is equal to its actual concentration in the receiving water body during the production of the products. Therefore, the operational grey water footprint becomes zero. We introduce this assumption as the wastewater treatment levels in the Netherlands and Belgium are very high and the regulations for treatment of industrial wastewater are very strict. Additionally, this assumption has a very little effect on the total water footprint of the products (less than 1%). Second assumption is that there is no water loss in the production processes. The water balance recordings of the

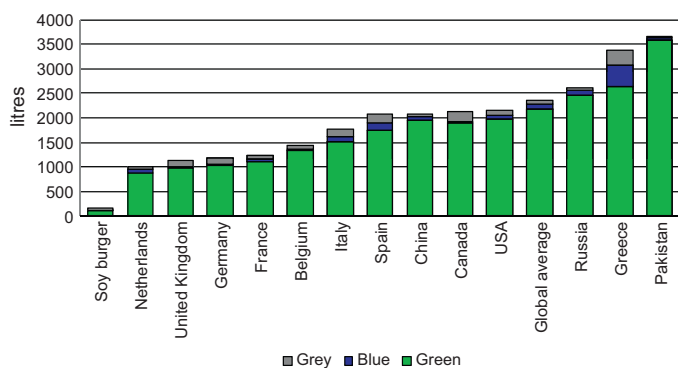


Fig. 8. The water footprint of 150 g of soy burger compared to the water footprint of 150 g of beef burger from various locations (in l).

factories indicate that water intake is almost equal to the wastewater discharge from the factories. Therefore, our assumption is very close to the real case. Another assumption is that vanilla extract used in the products is single folded. It might be the case that vanilla extract is multi folded; however the effect of this to the total water footprint of soy burger is negligible.

This study only focuses accounting phase of water footprint assessment and excludes impact assessments. For a more in-depth analysis of the local environmental and social impacts of water footprints of products, one would have to analyse the water footprints in their geographic context, considering for example local water scarcity and pollution and effects on local ecosystems and social conflict. In the current study, this has not been done because the interest was not to study local impacts, but to compare the claims on freshwater resources of soy products versus equivalent animal products and to consider how the type of agricultural practice (organic versus non-organic; rainfed versus irrigated) can influence freshwater claims as well. Additionally we did not assess and take the environmental damages due to extensive soybeans production into consideration. Some possible damages can be deforestation, land degradation and soil pollution (WWF, 2003). Our analysis also does not reflect the human needs for nutrients such as proteins, calcium. It may be the case that more soy-product is required to fully match the nutrients that is taken from animal products.

The case of French farms is a good example of how irrigation can affect the water footprint value. The two French farms are located in the same region with similar climatic conditions. However, the first farm irrigates its field to obtain higher yields and the second farm cultivates soybean only with rainwater. The comparison of the water footprints shows that soybeans from the irrigated farm have a smaller total water footprint (14%), but the irrigated soybeans have a five times larger blue water footprint and a larger grey water footprint as well. This result is important, as generally competition over blue water resources is larger (i.e. they are scarcer), so that it may well be that from both an economic and environmental point of view the benefit of the reduced blue and grey water footprints in rainfed farming exceeds the cost of the increased green water footprint. Obviously, the analysis presented here is a partial one, focussed on showing green and blue water consumption and pollution; for a complete assessment of rainfed versus irrigated farming one needs to take other relevant factors into account as well, like the costs of both practices and the scarcity of (i.e. the competition over) both the green and blue water resources.

In the example of soy bean cultivation in France, there is space for improving rainfed soybean yields and therefore reducing the water footprint. This could be done in number of ways, for example by selecting high-yielding, well-adapted varieties, controlling weeds prior to planting, planting at the optimum seeding rates, depth and timing, harvesting at the optimum stage and adjusting combine settings (Staton et al., 2010). The grey water footprint could also be reduced by shifting to integrated or organic farming systems.

Organic farmers grow crops without using synthetic pesticides or fertilizers, relying instead on a wide range of cultural practices and alternative inputs believed to be safer for the environment and the consumer. Soybeans are relatively easy to produce using organic methods. However, it is important to recognize that organic farms rarely focus on a single crop. Organic soybean is grown in rotation with several other crops that (ideally) complement or compensate for one another. Crop rotations serve two primary purposes: to improve soil fertility and to break pest cycles. With regard to fertility management, rotation strategies concentrate mainly on generating and conserving nitrogen. Nitrogen is commonly the most limiting element in organic production, especially for corn and small grains, which complement soybeans in most crop sequences.

Crop rotations that include forage legumes are the key where nitrogen is supplied to the system (NCAT, 2004). Organic production has slightly lower water consumption because the evapotranspiration from the field is less (Allen et al., 1998) and results in much less pollution because the load of chemicals to groundwater and surface water is less. Organic production systems also have other environmental benefits beside grey and blue water footprint reductions. Organic agricultural production systems also have lower ecological footprints (Niccolucci et al., 2008).

The current study is not based on field measurements of water consumption and leaching of applied chemicals, but based on statistics supplied by the farms and simple models to estimate evapotranspiration and water pollution. The figures presented should therefore be considered as very rough first estimates only.

5. Conclusions

This study shows the importance of a detailed supply-chain assessment in water footprint accounting. Food processing industries commonly consider water use in their own operations only. If they have water use reduction targets, those targets are formulated with regard to their own water use. With examples for two soybean products, this study shows that, however, the operational water footprint is almost negligible compared to the supply-chain water footprint. For a food processing company, it is crucial to recognize farmers as key players if the aim is to reduce the overall water consumption and pollution behind final food products. Engaging with farmers and providing positive incentives for the adoption of better agricultural practices are an essential element in a food company's effort to make its products sustainable.

The results of the study show that the water footprint of a soy product is very sensitive to where the inputs of production are sourced from and under which conditions the inputs are produced. This is most in particular relevant for the agricultural inputs. The water footprints of soy milk and soy burger depend significantly on the locations of the farms producing the soybean and on the agricultural practices at these farms (organic versus non-organic and rainfed versus irrigated). Not only the total water footprint, but also the colour composition (the ratios green, blue, grey) strongly varies as a function of production location and agricultural practice. These results reveal the importance of the spatial dimension of water accounting.

For the limited number of cases that we have considered, we find that non-organic soybean has a larger water footprint (ranging between 2145 and 3172 m³/ton) than organic soybean (1520–2024 m³/ton). Organic agriculture, apart from having a lower evapotranspiration, reduces the grey water component. Shifting towards organic production will reduce the grey water footprint of agricultural production and thus the damage to aquatic life and ecosystems. Another factor that can be influenced is the degree of irrigation. In the case of the two French farms considered in this study, the total water footprint is larger for rainfed soybean, but the blue water footprint of rainfed soybean is zero.

The study shows that soy milk and soy burger have much smaller water footprints than their equivalent animal products. The water footprint of the soy milk product analysed in this study is 28% of the water footprint of the global average cow milk. The water footprint of the soy burger examined here is 7% of the water footprint of the average beef burger in the world.

References

Allen, R.G., Pereira, L.S., Raes, D., Smith, M., 1998. Crop Evapotranspiration – Guidelines for Computing Crop Water Requirements FAO Irrigation and Drainage Paper 56. Food and Agriculture Organization, Rome.

Chapagain, A.K. and Hoekstra, A.Y. 2004. Water footprints of nations, Value of Water Research Report Series No. 16, UNESCO-IHE, Delft, the Netherlands.

De Fraiture, C., Wichelns, D., Rockström, J., Kemp-Benedict, E., Eriyagama, N., Gordon, L.J., Hanjra, M.A., Hoogeveen, J., Huber-Lee, A., Karlberg, L., 2007. Looking ahead to 2050: scenarios of alternative investment approaches. In: Molden, D. (Ed.), Water for Food, Water for Life: A Comprehensive Assessment of Water Management in Agriculture. International Water Management Institute, Colombo, Earthscan, London, pp. 91–145.

Doussset, S., Chauvin, C., Durlot, P., Thevenot, M., 2004. Transfer of hexazinone and glyphosate through undisturbed soil columns in soils under Christmas tree cultivation. Chemosphere 57, 265–272.

EPA, 2010. National Recommended Water Quality Criteria, United States Environmental Protection Agency.

Ercin, A.E., Aldaya, M.M., Hoekstra, A.Y., 2011. Corporate water footprint accounting and impact assessment: the case of the water footprint of a sugar-containing carbonated beverage. Water Resources Management 25 (2), 721–741.

Eriksen, J., Askegaard, M., 2000. Sulphate leaching in an organic crop rotation on sandy soil in Denmark. Agriculture Ecosystems and Environment 78, 107–114.

FAO, 2009a. CROPWAT 8.0 Model. Food and Agriculture Organization, Rome.

FAO, 2009b. CLIMWAT 2.0 Database. Food and Agriculture Organization, Rome.

FDA, 2006. Code of Federal Regulations. Title 21, Part 169.175, Washington, D.C.

Galloway, J., Burke, M., Bradford, G.E., Naylor, R., Falcon, W., Chapagain, A.K., Gaskell, J.C., McCullough, E., Mooney, H.A., Oleson, K.L.L., Steinfeld, H., Wassenaar, T., Smil, V., 2007. International trade in meat: the tip of the pork chop. Ambio 36, 622–629.

Hoekstra, A.Y. (ed.). 2003. Virtual water trade: Proceedings of the International Expert Meeting on Virtual Water Trade, Delft, The Netherlands, 12–13 December 2002. Value of Water Research Report Series No. 12, UNESCO-IHE, Delft, the Netherlands.

Hoekstra, A.Y., 2010. The water footprint of animal products. In: D'Silva, J., Webster, J. (Eds.), The Meat Crisis: Developing more Sustainable Production and Consumption. Earthscan, London, UK, pp. 22–33.

Hoekstra, A.Y., Chapagain, A.K., 2008. Globalization of Water: Sharing the Planet's Freshwater Resources. Blackwell Publishing, Oxford, UK.

Hoekstra, A.Y., Chapagain, A.K., Aldaya, M.M., Mekonnen, M.M., 2011. The Water Footprint Assessment Manual: Setting the Global Standard. Earthscan, London, UK.

Kjær, J., Olson, P., Henriksen, T., Ullum, M., 2005. Leaching of metribuzine metabolites and the associated contamination of a sandy aquifer. Environmental Science & Technology 39 (21), 8374–8381.

MacDonald, D.D., Berger, T., Wood, K., Brown, J., Johnsen, T., Haines, M.L., Brydges, K., MacDonald, M.J., Smith, S.L., Shaw, D.P., 1999. A compendium of environmental quality benchmarks. In: MacDonald Environmental Sciences. Nanaimo, British Columbia, Canada.

MDEQ (Ministere de l'Environnement du Quebec). 1996. Chimères de qualité de l'eau de surface au Quebec. Quebec City, Quebec.

Mekonnen, M.M., and Hoekstra, A.Y. 2010a. The green, blue and grey water footprint of crops and derived crop, Value of Water Research Report Series No. 47, UNESCO-IHE, Delft, the Netherlands.

Mekonnen, M.M., and Hoekstra, A.Y. 2010b. The green, blue and grey water footprint of farm animals and animal products, Value of Water Research Report Series No. 48, UNESCO-IHE, Delft, the Netherlands.

Monfreda, C., Ramankutty, N., Foley, J.A., 2008. Farming the planet: 2. Geographic distribution of crop areas, yields, physiological types, and net primary production in the year 2000. Global Biogeochemical Cycles 22, GB1022.

NCAT. 2004. Organic crop production overview. Fundamentals of sustainable agriculture, National Sustainable Agriculture Information Service, The National Center for Appropriate Technology.

Niccolucci, V., Galli, A., Kitzes, J., Pulselli, R.M., Borsari, S., Marchettini, N., 2008. Ecological footprint analysis applied to the production of two Italian wines. Agriculture Ecosystems and Environment 128, 162–166.

Peden, D., Tadesse, G., Misra, A.K., Ahmed, F.A., Astatke, A., Ayalneh, W., Herrero, M., Kiyuwa, G., Kumsa, T., Mati, B., Mpairwe, D., Wassenaar, T., Yimegnuh, A., 2007. Water and livestock for human development. In: Molden, D. (Ed.), Water for food, water for life: a comprehensive assessment of water management in agriculture. International Water Management Institute, Colombo, Earthscan, London, pp. 485–514.

Pegram, G., Orr, S., Williams, C., 2009. Investigating Shared Risk in Water: Corporate Engagement with the Public Policy Process. WWF, Godalming, UK.

Persicani, D., Gasparetti, G., Siro, P., Bonvini, M., 1995. Measurement and simulation of atrazine and alachlor leaching into two field soils. Journal of Contaminant Hydrology 19, 27–144.

Rondinelli, D.A., Berry, M.A., 2000. Environmental citizenship in multinational corporations: social responsibility and sustainable development. European Management Journal 18 (1), 70–84.

Singh, N., 2003. Organic manure and urea effect on metolachlor transport through packed soil columns. Journal of Environmental Quality 32, 1743–1749.

Stites, W., Kraft, G.L., 2001. Nitrate and chloride loading to groundwater from an irrigated north-central US sand-plain vegetable field. Journal of Environmental Quality 30, 1176–1184.

Staton, M., Thelen, K., Silva, G., 2010. Soybean facts: checklist for improving soybean yields, Michigan State University Extension. Michigan Soybean Promotion Committee, February 2010.

Steinfeld, H., Gerber, P., Wassenaar, T., Castel, V., Rosales, M., de Haan, C., 2006. Livestock's long shadow: environmental issues and options. Food and Agriculture Organization, Rome.

- UNESCO, 2006. *Water a Shared Responsibility: the United Nations World Water Development Report 2*. UNESCO Publishing, Paris/Berghahn Books, Oxford.
- Van der Leeden, F., Troise, F.L., Todd, D.K., 1990. *The Water Encyclopaedia*, 2nd edition. CRC Press, Boca Raton, FL, USA.
- Van Oel, P.R., and Hoekstra, A.Y. 2010. The green and blue water footprint of paper products: methodological considerations and quantification, Value of Water Research Report Series No. 46, UNESCO-IHE, Delft, the Netherlands.
- WWF, 2003. *Soy Expansion – Losing Forests to Fields*, WWF Forest Conversion Initiative. World Wild Fund, Switzerland.