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Water footprint benchmarks for crop production

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WATER FOOTPRINT BENCHMARKS FOR CROP PRODUCTION

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Summary

In the coming few decades, global freshwater demand will increase to meet the growing demand for food, fibre and biofuel crops and this increase needs to be met under increasing freshwater scarcity. Raising water productivity or reducing the water footprint in agriculture is believed to offer solutions to address the increasing pressure on the global freshwater resources. This study establishes a set of global water footprint benchmark values for a large number of crops grown in the world.

The study distinguishes between benchmarks for the green-blue water footprint (the sum of rain- and irrigation water consumption) and the grey water footprint (volume of polluted water). The reference period is the average over the years 1996-2005. The approach has been to analyse the spatial distribution of the green-blue and grey water footprints of different crops as calculated at a spatial resolution of 5 by 5 arc minute with a dynamic water balance and crop yield model. Per crop, we ranked the water footprint values for all relevant grid cells from smallest to largest and plotted these values against the cumulative percentage of the corresponding production.

The study shows that if we would reduce the green-blue water footprint of crop production everywhere in the world to the level of the best 25th percentile of current global production, there would be a water saving in global crop production of 39% compared to the reference water consumption. With a reduction to the water footprint levels of the best 10th percentile of current global production, the water saving would be 52%. In the case that nitrogen-related grey water footprints in crop production are reduced, worldwide, to the level of the best 25th percentile of current global production, water pollution is reduced by 54%. If grey water footprints per ton of crop are further reduced to the level of the best 10th percentile of current production, water pollution is reduced by 79%.

The benchmark values provide valuable information for formulating water footprint reduction targets in crop production. Further studies will be required to test the sensitivity of the benchmark values to the underlying model assumptions, to see whether regionalization of benchmarks is necessary and how certain water footprint benchmark levels relate to specific technology and agricultural practices.

1. Introduction

Agriculture is the largest freshwater user, accounting for 99% of the global consumptive (green plus blue) water footprint (Hoekstra and Mekonnen, 2012). Growing populations, coupled with changing preferences in diets and rising demand for biofuels, will put increasing pressure on the globe's freshwater resources (Gleick, 2003; Falkenmark et al, 2009; Rosegrant et al, 2009). The consumptive water use (from both precipitation and irrigation) for producing food and fodder crops is expected to increase at 0.7% per year from its estimated level of 6400 Gm^3/yr in 2000 to 9,060 Gm^3/yr in order to adequately feed the global population of 9.2 billion by 2050 (Rosegrant et al., 2009). The growing freshwater scarcity is already evident in many parts of the world (Gleick, 1993; Postel, 2000; Oki and Kanae, 2006; Vörösmarty et al., 2010, Wada et al., 2011; Hoekstra et al., 2012).

Raising water productivity ("more crop per drop") in agriculture can offer solutions to address the increasing pressure on the global freshwater resources (Rockström, 2003; Passioura, 2006). The water footprint (WF) offers a quantifiable indicator to measure the volume of water consumption per unit of crop, as well as the volume of water pollution (Hoekstra and Chapagain, 2008; Hoekstra et al., 2011). The green WF measures the volume of rainwater consumed during the growing period of the crop; the blue WF measures the volume of surface and groundwater consumed. Consumption refers to the amount of water evaporated from the crop field plus the amount of water stored in the plant harvested (the latter is very small, though). The grey WF measures the volume of freshwater that is required to assimilate the nutrients and pesticides leaching and running off from crop fields and reaching groundwater or surface water, based on natural background concentrations and existing ambient water quality standards (Hoekstra et al., 2011).

Water footprint benchmarks for crop production can be an instrument to compare actual water footprints in certain regions or even at field level to certain reference levels and can form a basis to formulate water footprint reduction targets, aimed to decrease water consumption and pollution per unit of crop (Hoekstra, 2013a, 2013b). The water footprint of crops varies enormously across regions and within regions (Hoekstra and Chapagain, 2007; Siebert and Döll, 2010; Mekonnen and Hoekstra, 2011; Fader et al., 2011; Brauman et al., 2013; Finger, 2013). There are no previous studies that aimed to develop benchmarks for the water footprint of crops, but a number of studies exist on benchmarking water productivities. The water productivity (ton/m^3) in crop production is in fact the inverse of the green-blue water footprint (m^3/ton) of crop production. Water productivity studies can be grouped into four classes: field studies, modelling studies, studies based on remote sensing, and studies employing a combination of field measurement and modelling or satellite data. In field studies, the relationship between seasonal water use and crop yield is determined from field measurements (Rahman et al., 1995; Sharma et al., 1999, 2001; Zhang et al., 1998, 1999; Oweis et al., 2000; Sadras et al., 2007). Water productivity studies based on field measurements are limited to experiments on a relatively small number of fields, so that results are always limited to local conditions such as climate, soil characteristics and water management practices and cannot easily be scaled up for larger areas. In modelling studies, soil water balance and crop growth models are used to estimate the components of the seasonal crop water balance (Amir and Sinclair, 1991; Asseng et al, 1998, 2001). The limitation of model studies is that they generally do not account for all constraining factors and may exclude some important factors such as pests, diseases and weeds and their use is limited by data availability and quality (Grassini et al., 2009). Remote sensing studies use satellite data to estimate the spatial variation of water productivity (Zwart and Bastiaanssen, 2007; Biradar, 2008; Cai et al., 2009; Zwart et al., 2010a, 2010b). The use of remote sensing allows estimating the water productivity over large areas. A number of studies combined measured data with simulation models (Sadras et al., 2003; Robertson and Kirkegaard, 2005; Grassini et al., 2009) and others combined measured data with remote sensing data (Cai and Sharma, 2010). While crop water productivity is receiving an increasing amount of attention, minimizing water pollution (the grey water footprint) per unit of crop production receives much less attention. It is clear, though, that the grey water footprint per unit of crop varies greatly from place to place depending on agricultural practices (Chapagain et al., 2006; Mekonnen and Hoekstra, 2010, 2011).

To our knowledge, there has been no previous study providing global benchmark values for green-blue and grey water footprints of crops. The studies cited above are limited to either a few crops or specific locations. The objective of the current study has been to develop global water footprint benchmark values for 124 crops based on the spatial variability of crop water footprints as found in our earlier global water footprint assessment of crop production (Mekonnen and Hoekstra, 2011).

2. Method and data

The study distinguishes between benchmarks for the green-blue water footprint and the grey water footprint of crops. The approach has been to analyse the spatial distribution of the green-blue and grey water footprints of different crops as calculated at a spatial resolution of 5 by 5 arc minute with a dynamic water balance and crop yield model. Details on the model used have been reported in Mekonnen and Hoekstra (2010, 2011). Basically, the model computes a daily soil water balance and calculates crop water requirements, actual crop water use (both green and blue) and actual yields. Green-blue water footprints are calculated by dividing the evapotranspiration of green and blue water over the growing period by the crop yield. Grey water footprints are calculated based on nitrogen application rates, leaching-runoff fractions and water quality standards for nitrate. We did not consider the grey water footprint from other nutrients (like phosphorous) or pesticides. The model was applied at a global scale for the period 1996-2005. In total, 124 crops were studied.

We first analysed the water footprint of wheat in terms of m^3/ton at three different spatial resolution levels – country, provincial and grid level – in order to identify the proper spatial resolution for developing water footprint benchmarks for crop production. After choosing the grid level as the best option for further analysis, the variability in water footprints of crops over all crop growing grid cells in the world was used for developing the benchmarks. Per crop, we ranked the water footprint values for all relevant grid cells from smallest to largest and plotted these values against the cumulative percentage of the corresponding production. From the graph, we could thus read the water footprint values at different production percentiles.

For an analysis of differences in water footprints between developing versus industrialised countries, we used the country classification based on income from the World Bank (2012), in which countries are divided according to the 2007 per capita gross national income (GNI). The groups are: low income (USD 935 or less), lower middle income (USD 936-3705), upper middle income (USD 3706-11455) and high income (USD 11456 or more).

In order to analyse differences in water footprints between different climatic regions, we used the Köppen-Geiger climate classification (Kottek et al., 2006) to group the world into four major climate classes: tropics (arid and equatorial), temperate, boreal (snow) and tundra (polar). Appendix I shows a map of these climate classes. Since little or no crop cultivation exists in the boreal and tundra regions of the world, in this study we have focused only on the tropics and temperate regions.

3. Results

3.1. The distribution of the green-blue water footprint of wheat at three spatial resolutions

The distribution of the green-blue water footprint (WF) of wheat was analysed at three different spatial scales by considering the average green-blue WF in m^3/ton and production data in ton/yr at country, provincial and grid level. Figures 1-3 have been obtained by plotting the green-blue WF, sorted from smallest to largest, against the cumulative percentage of the production. Although the figures for the three spatial scales of analysis show similar patterns, the points in the country-scale analysis (Figure 1) do not form a smooth curve like the points in the provincial-scale (Figure 2) and grid-scale analysis (Figure 3). This is because of the limited number of points in the country-scale analysis. We can observe that the green-blue WF values at the respective production percentiles decrease when moving from the country to the grid level. In addition, we see that the WF at the 50th percentile of production is not necessarily equal to the global average WF, which is a characteristic of any skewed distribution. As we can see from the grid-based analysis, the variability of the WF of the best half of the global wheat production is smaller than the variability of the WF of the worst half, so that the global average WF (1620 m^3/ton) turns out to be larger than the WF at the 50th percentile of production (1391 m^3/ton). The latter value means that 50% of global wheat production occurs at a green-blue WF of 1391 m^3/ton or less.

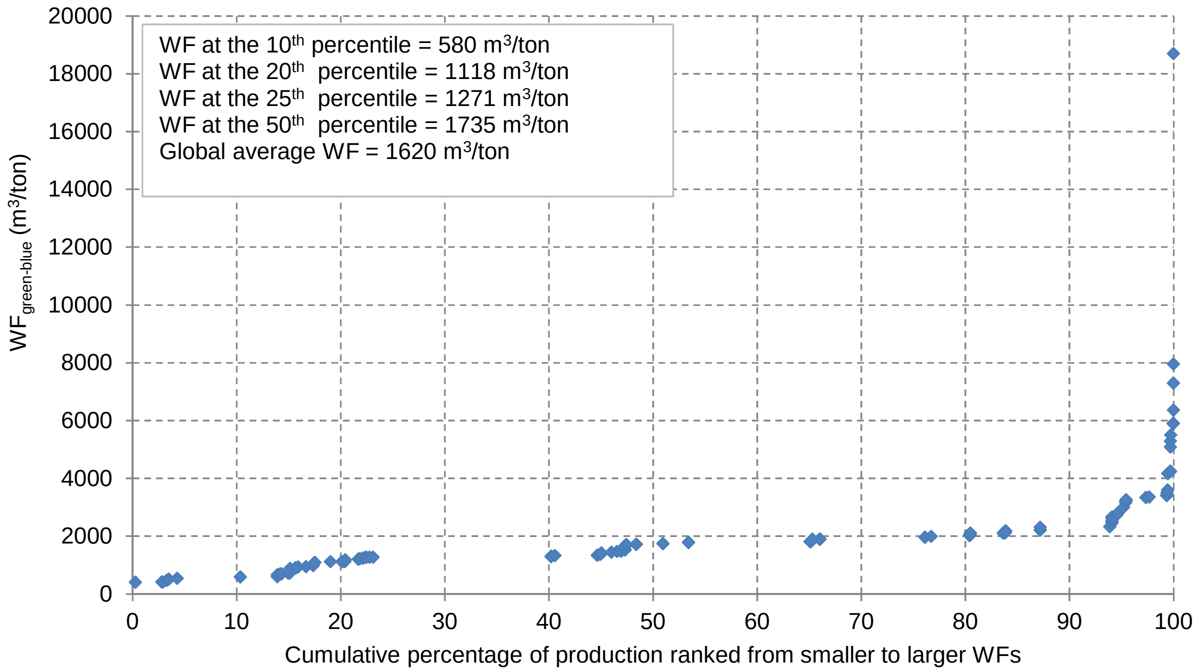


Figure 1. Green-blue WF of wheat (in m^3/ton) for all wheat-producing countries in the world, plotted from smallest to largest WF.

There are two reasons that favour the grid over the provincial or country level analysis. First, particularly the country level analysis is weak as it provides a very dispersed curve and the analysis will get even weaker for crops which are grown in only a few countries. Second, there can be significant WF differences within provinces and countries, which are hidden in the analysis at those levels. The averages at provincial and even more so at country level are generally biased towards the worse footprints (because of the skewed distributions), so that the WFs at the various production percentiles found with the grid-based analysis are closer to reality than in case of the analyses at the lower resolution levels. Therefore, for the remainder of this study, we analyse the distribution of crop WFs at the grid level.

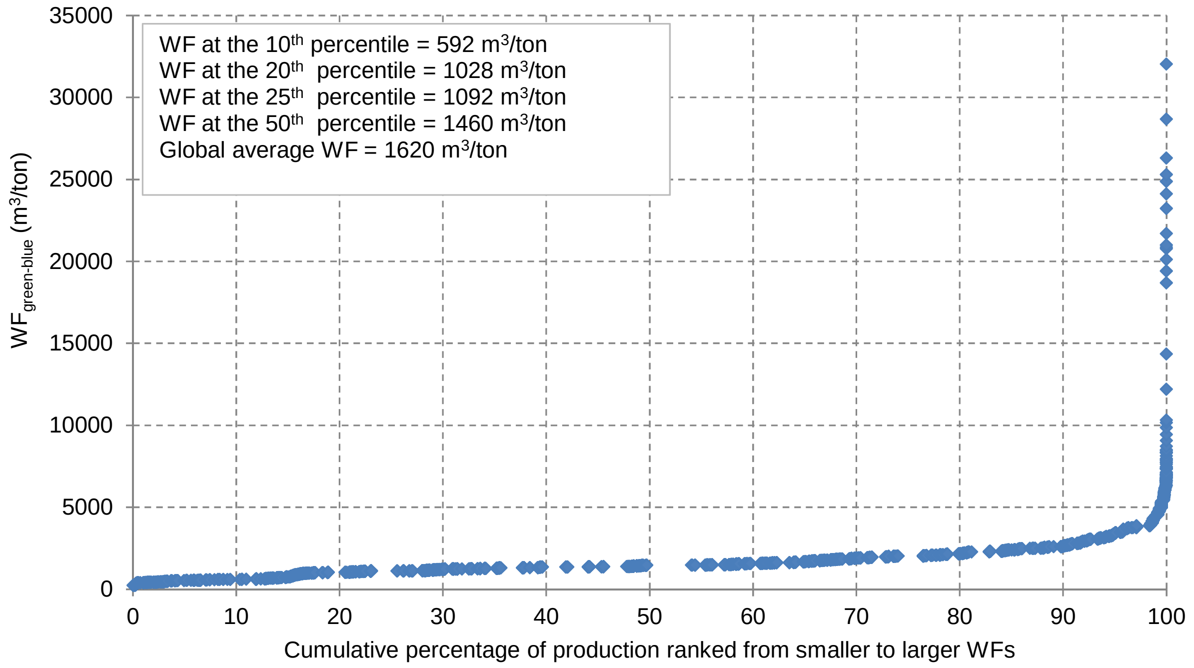


Figure 2. Green-blue WF of wheat (in m^3/ton) for all wheat-producing provinces in the world, plotted from smallest to largest WF.

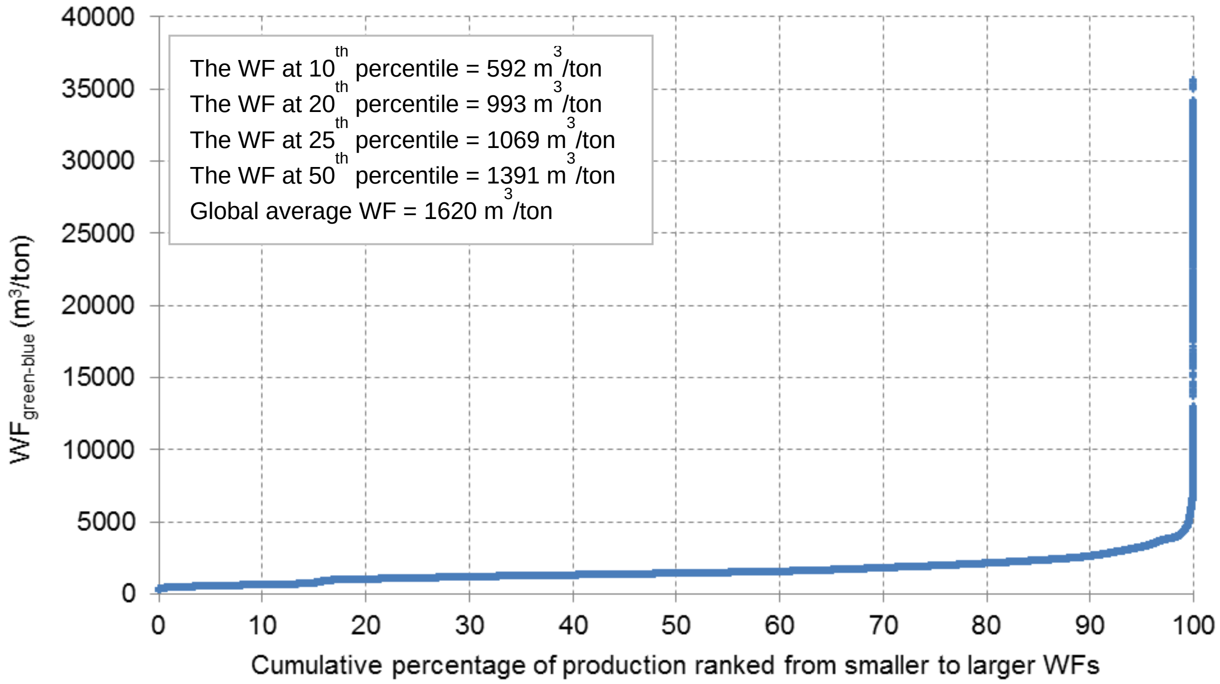


Figure 3. Green-blue WF of wheat (in m^3/ton) for all wheat-producing grid cells in the world, plotted from smallest to largest WF.

3.2. The green-blue water footprint of different crops at different production percentiles

The distribution of the green-blue WF for ten selected crops at different production percentiles is shown in Table 1. The values were derived by plotting the green-blue WF of the respective crops from smallest to largest WF against the cumulative percentage of crop production (Appendix II). The curves in Appendix II are relatively flat in the first (best) half of the global production. The second (worst) half of the global production shows a steeper curve, with very large WF values for the last 10-20% of production. As a result, the WF at the 50th percentile of production is generally smaller than the global average WF, as was already explained in the previous section for the case of wheat. Appendix III provides the green-blue WF at different production percentiles for all 124 crops studied.

Table 1. Green-blue water footprint for a few selected crops at different production percentiles.

Crop	Green-blue water footprint (m^3/ton) at different production percentiles				Global average
	10th	20th	25th	50th	
Barley	447	516	546	1029	1292
Cotton	1666	1821	1898	2880	3589
Maize	503	542	562	754	1028
Millet	2292	2741	2905	3653	4363
Potatoes	92	137	154	216	224
Rice	599	859	952	1476	1486
Sorghum	1001	1082	1122	1835	2960
Soybean	1553	1605	1620	1931	2107
Sugar cane	112	123	128	175	197
Wheat	592	992	1069	1391	1620

The maps in Figure 4 show the spatial variability of the green-blue WF of the ten selected crops across the world. The ranges are chosen such that one can easily see in which parts of the world, production occurs at WFs in the range of the best 10% of global production, etc. One can immediately see that relatively small WFs are not inherent to high-income countries or humid regions and that large WFs are not intrinsically connected to low-income countries or (semi-)arid regions. This is more precisely shown in Table 2. Although low WFs as found in the best 10 to 20% of global production are mostly found in high income and temperate regions, we can find the different percentiles in all parts of the world, also in low income and tropical regions. High-income countries have a greater capacity to implement best available technology and best practices than less developed countries, but the presence of the best percentiles of production in the less developed and tropical countries indicates that reduction of WFs to the best 10th percentile of current global production is technically feasible everywhere.

Based on our data, we can develop benchmark values per country rather than for the world as a whole, but one may question the value of such national benchmarks. As an example, we consider wheat production in three different big countries. Figure 5 shows the green-blue WF of wheat production in China, India and the USA as a function of cumulative production. Most of the wheat in the three countries is produced in temperate regions (about 79% in China, 64% in India and 63% in the USA). The WFs at different production percentiles in the three countries are larger than in the global case (Figure 3). As the USA case shows, high income does not imply small WFs: both China, which is a lower middle income country, and India, a low income country, have smaller WFs in wheat production than the USA. Although income may play a significant role in the capacity of countries to reduce WFs in crop production, it would not be appropriate to propose different water footprint benchmark values based on the income of countries.

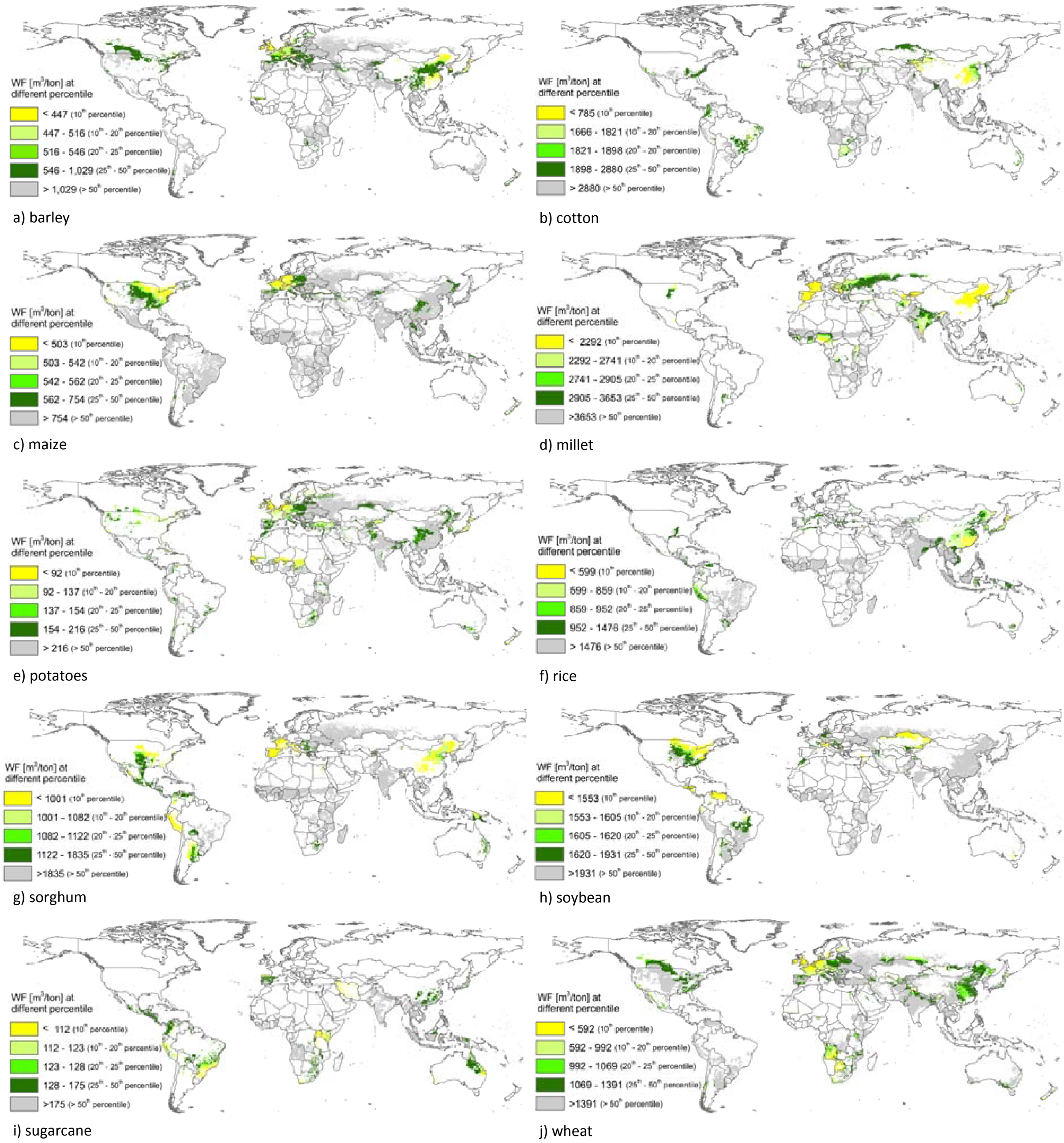


Figure 4. Spatial distribution of the green-blue water footprint of selected crops (in m^3/ton), classified based on the WFs at the different production percentiles.

Table 2. Percentage of grid cells in different income and climate regions in which crops have a WF below the WF at the 10th, 20th, 25th, or 50th percentile of global production.

Crop	Percentage of grid cells with WF below the 10th percentile					Percentage of grid cells with WF below the 20th percentile					Percentage of grid cells with WF below the 25th percentile					Percentage of grid cells with WF below the 50th percentile				
	Income class			Climate class		Income class			Climate class		Income class			Climate class		Income class			Climate class	
	Low income	Middle income	High income	Temperate	Tropics	Low income	Middle income	High income	Temperate	Tropics	Low income	Middle income	High income	Temperate	Tropics	Low income	Middle income	High income	Temperate	Tropics
Barley	1	4	9	9	1	1	6	17	15	2	1	7	22	18	3	10	26	63	47	11
Cotton	1	9	3	12	2	2	18	7	21	5	2	22	8	25	6	7	48	52	56	18
Maize	0	0	27	8	0	0	0	38	12	0	0	0	44	14	0	2	8	75	29	3
Millet	8	34	69	40	9	18	43	78	50	18	22	49	84	54	22	37	79	100	73	34
Potatoes	8	0	17	6	8	14	3	59	18	13	15	5	71	23	16	26	28	95	47	30
Rice	0	5	5	7	0	0	13	29	19	2	0	18	41	26	3	8	35	86	50	13
Sorghum	1	16	49	32	4	2	24	57	40	8	2	26	62	45	9	5	39	96	66	22
Soybean	0	10	26	12	9	0	11	36	15	10	0	11	39	16	10	1	20	73	27	21
Sugar cane	8	10	10	15	6	10	14	18	20	9	11	17	22	22	12	20	48	77	55	37
Wheat	0	2	11	5	3	5	8	23	13	9	7	14	25	17	11	20	33	46	40	22

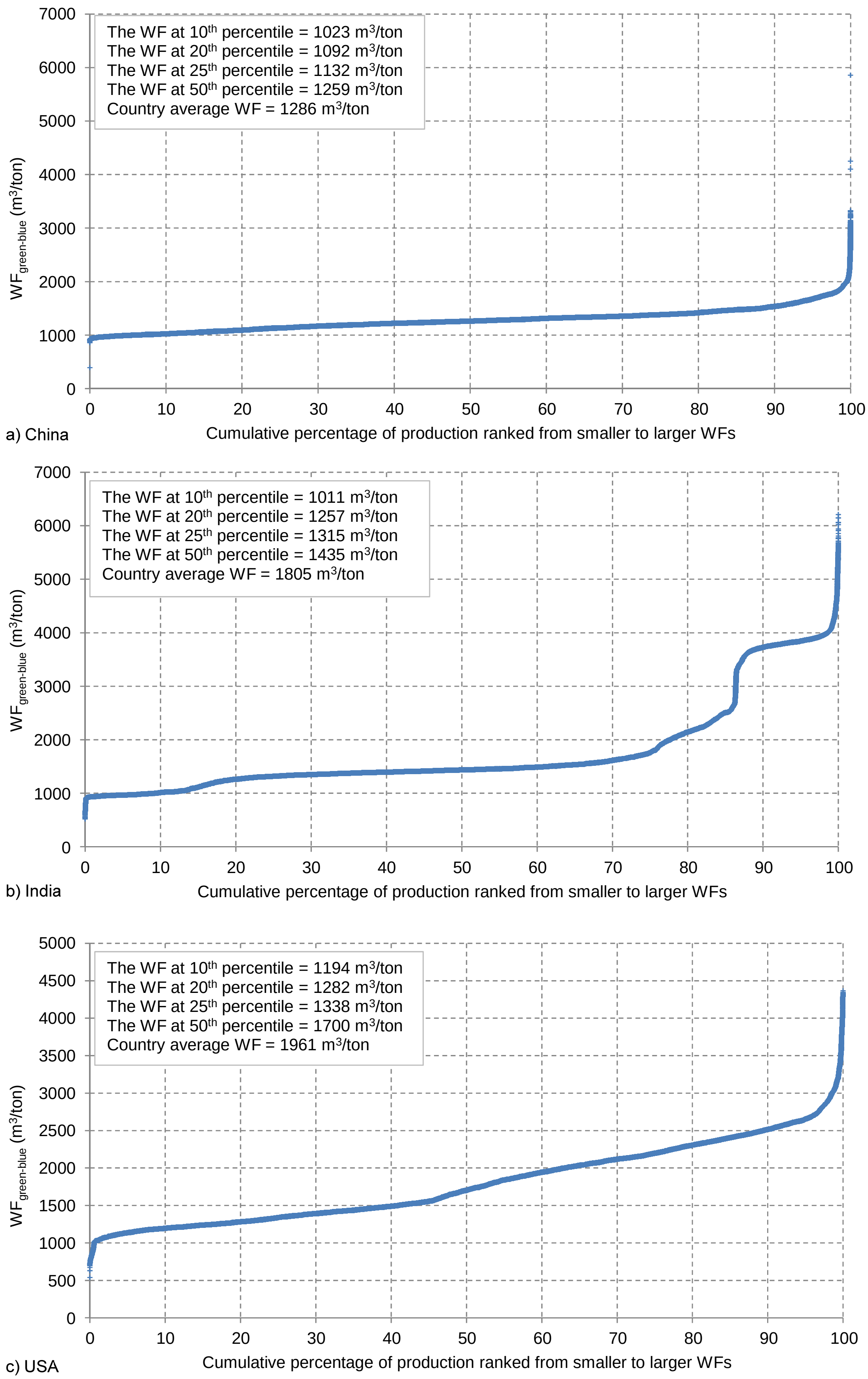
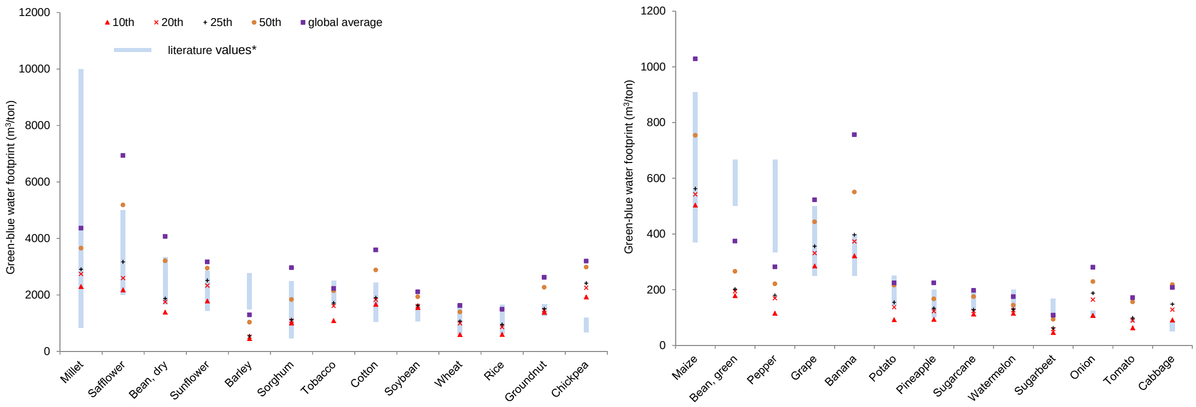


Figure 5. Green-blue WF of wheat (in m^3/ton) for all wheat-producing grid cells in China, India and the USA, plotted from smallest WF to largest WF.

In order to compare the results from this study with the literature, we collected data from a number of water productivity studies for different crops and locations. We used four publications (Doorenbos and Kassam, 1979; Hatfield et al, 2001; Zwart and Bastiaansen, 2004; Sadras et al, 2007) that summarize crop water productivities from various studies. Since the different studies relate to dissimilar climate and soil conditions and water management practices, the water productivity values for a given crop vary over a wide range. Figure 6 shows the inverse of the water productivity ranges collected from literature together with the green-blue WF at different production percentiles from the current study. In most cases, the ranges found in the literature overlap well with the values found in this study. In some cases, the lowest value found in the literature is substantially smaller than the WF at the best 10th percentile of global production (millet, sorghum, cotton, soybean, chickpea, maize, banana), while other cases show the reverse (barley, green bean, pepper, potato and sugar beet). The values from literature are too random and probably not representative enough to reflect global variability to draw any conclusions here based on the comparison. In general though it can be said that this study is the first in its sort and that it will be useful to study the sensitivity of the benchmark values presented here to the underlying model and data.



* Sources of the literature values: wheat, maize, rice and cotton from Zwart and Bastiaanssen (2004); sorghum, millet, soybean, sunflower from Sadras et al. (2007); barley and chickpea from Hatfield et al. (2001); the rest from Doorenbos and Kassam (1979).

Figure 6. Comparison of the green-blue WF of selected crops at different production percentiles with values reported in literature.

3.3. The grey water footprint of different crops at different production percentiles

The nitrogen-related grey WF for ten selected crops at different production percentiles is presented in Table 3. The grey WF for these crops as a function of cumulative production is shown in Appendix IV. The variability in the grey WF across crops and space is mainly due to differences in nitrogen application (kg/ha) and crop yield (ton/ha). The grey WF at different production percentiles for all crops is provided in Appendix V.

Application of nitrogen fertilizer influences crop water productivity by affecting the rate of photosynthesis, canopy size and the harvest index (Sadras et al., 2007). Nitrogen application generally increases grain yield and water productivity significantly (Belder et al., 2005), but the increase in crop yield and water productivity is achieved only up to a certain level of fertilization (Sandhu et al., 2012). Ensuring adequate nitrogen supply is critical for good water productivity, but only a fraction of the applied nitrogen fertilizer is recovered by plants

(Addiscot, 1996; King et al., 2001; Ma et al., 2009; Noulas et al., 2004) and on average about 16% of the applied nitrogen is presumed to be lost either by denitrification or leaching (Addiscot, 1996). Therefore, there is a trade-off between higher crop water productivity and increasing water pollution resulting from the loss of nitrogen to the freshwater system. This trade-off needs to be considered carefully because maximizing water productivity may result in deteriorating water quality through nutrient pollution.

Table 3. Grey water footprint at different production percentiles.

Crop	Grey water footprint (m^3/ton) at different production percentiles				Global average
	10th	20th	25th	50th	
Barley	23	53	64	121	131
Cotton	0	63	175	469	440
Maize	71	128	138	171	194
Millet	0	0	0	63	115
Potatoes	16	22	24	38	63
Rice	71	129	162	215	187
Sorghum	0	0	0	40	87
Soybean	9	9	10	11	37
Sugar cane	3	7	8	11	13
Wheat	27	82	99	144	208

3.4. Water saving and reduced water pollution when reducing water footprints down to benchmark values

Table 4 presents the global green-blue water saving that could be achieved when, worldwide, the WF in crop production would be brought down to certain benchmark values. As benchmark values, we have used the water footprints associated with the best 10th, 20th, 25th and 50th percentile of current production. The global water saving related to improved water productivity in crop production increases when the WF benchmark values get smaller (from the 50th to the 10th percentile). If the gap between current WF levels and the global benchmark values at the 25th percentile of current production is eliminated, the global water saving would be 39%. In absolute terms, the largest WF reduction is observed for cereal crops: wheat (375 Gm^3/yr), rice (350 Gm^3/yr), maize (296 Gm^3/yr), sorghum (111 Gm^3/yr) and barley (110 Gm^3/yr). In the case of further reduction to the levels of the best 10th percentiles of current global production, the global water saving would be 52% compared to today. The potential reduction of the green-blue WF related to crop production for all crops is presented in Appendix VI.

The possible reductions in water pollution (grey WF) are even greater than the possible reductions in consumptive water use (green-blue WF), as shown in Table 5. In the case that grey WFs in crop production are reduced, worldwide, to the level of the best 25th percentile of current global production, water pollution is reduced by 54%. If grey WFs per ton of crop are further reduced to the level of the best 10th percentile of current production, water pollution is reduced by 79% compared to today's pollution level.

Table 4. Global green-blue water saving if everywhere the water footprint of crop production is reduced to the level of the best 10th, 20th, 25th or 50th percentile of current production.

Crop	Global total green-blue water footprint (billion m^3/yr)	Green-blue water saving (%) in the case of worldwide WF reduction to the level of the best x^{th} percentile of current production			
		10^{th}	20^{th}	25^{th}	50^{th}
Barley	184	66	61	60	36
Cotton	207	54	50	49	30
Maize	648	51	48	46	35
Millet	126	49	39	36	25
Potatoes	70	59	42	36	17
Rice	881	60	44	40	18
Sorghum	177	67	64	63	50
Soybean	363	26	24	23	15
Sugar cane	254	43	38	35	21
Wheat	964	64	43	39	25
Others	2750	47	40	37	23
Total	6625	52	42	39	25

Table 5. Reduced water pollution if everywhere in the world the grey water footprint of crop production is reduced to the level of the best 10th, 20th, 25th or 50th percentile of current production.

Crop	Global total grey water footprint (billion m^3/yr)	Reduced water pollution (%) in the case of worldwide grey WF reduction to the level of the best x^{th} percentile of current production			
		10^{th}	20^{th}	25^{th}	50^{th}
Barley	19	83	63	57	27
Cotton	25	100	88	68	31
Maize	122	65	40	36	23
Millet	3	100	100	100	70
Potatoes	20	76	67	64	50
Rice	111	64	38	24	4
Sorghum	5	100	100	100	70
Soybean	6	76	76	74	73
Sugar cane	17	78	52	46	30
Wheat	123	88	65	58	43
Others	280	85	73	68	42
Total	732	79	61	54	33

4. Discussion

We have established global water footprint benchmark values instead of specific benchmarks for different agro-climatic or economic regions. One may argue that climatic factors can be a limiting factor for reducing the water footprint and different regional benchmark values should be established depending on climatic characteristics per region. However, although climatic factors are important in determining evapotranspiration from crop fields and yields, the green-blue water footprint of crops in m^3/ton is largely determined by agricultural management rather than by the agro-climate under which the crop is grown (Rockström et al., 2007; Mekonnen and Hoekstra, 2011). A large increase in crop yields, without an increase or even with a decrease in field evapotranspiration, is achievable for most crops across the different climate regions of the world through proper nutrient, water and soil management (Mueller et al., 2012). Therefore, water productivities as shown in the best 10^{th} percentile of global crop production can be achieved irrespective of climate, which is also shown in our comparison of water footprints of crops across different climate regions. The same sort of argument holds for low versus high-income countries. One may propose another (less strict) water footprint benchmark for low-income countries, with the argument that achieving a certain water productivity in a low-income country is more difficult than in a high-income country, but there are two arguments against that, First, reality shows that for most of the crops studied, the water productivities that can be associated with the best 10^{th} percentile of global crop production can be found in both low and high-income countries (Table 2). Second, there seems little reason to set other environmental standards for developing and industrialised countries, even though it can indeed be a greater challenge in developing countries to achieve certain improvements.

The current study has focussed on developing water footprint benchmark values for crop production based on the spatial variability in water footprints of crops worldwide, using the global assessment published earlier (Mekonnen and Hoekstra, 2011). The current study is the first proposing global water footprint benchmarks for crops based on such spatial variability analysis. It will be useful to carry out similar analyses with other models than the one used in Mekonnen and Hoekstra (2011) to test the sensitivities of the outcomes to the model used. In addition, as proposed by Hoekstra (2013a, 2013b), it would be useful to develop water footprint benchmarks from insights on what can be reached based on best available technology and practice. The current study shows the spatial distribution of water footprints in terms of m^3/ton based on regional differences in evapotranspiration and yields, but it provides no insight in why water footprints are relatively small or large in specific regions and how water footprints can actually be lowered in those regions where they are large.

As shown in Table 6, there are several strategies to increase crop water productivities and reduce the water footprint of crops. It would be highly valuable to develop insight in how various techniques and practices affect green, blue and grey water footprints in terms of m^3/ton, and how certain combinations of techniques and practices will be required to reduce water footprints to the benchmark values proposed in this study.

Table 6. Technology and practices to reduce the water footprint in crop production.

Strategies	Technology and practices
Increasing yield	▪ Soil nutrients management (optimizing crop rotation, the use of crop residues, erosion control, appropriate tillage, proper application and timing of manure or artificial fertilizer) ▪ Precision irrigation: synchronizing water application with crop water demand ▪ Weed and pest control (through crop rotation, proper tillage, biological pest control) ▪ Breeding of superior crop varieties with higher yield and better disease resistance
Reducing non-beneficial evapotranspiration	▪ Crop scheduling to reduce evaporation during fallow period ▪ Plant spacing and row orientation ▪ Affecting canopy development through agronomy and breeding ▪ Minimum tillage to reduce soil water evaporation and conserve soil water during fallow periods ▪ Use of crop residue and mulches to reduce soil water evaporation and improve nutrient recycling ▪ Improved irrigation techniques (drip & subsurface irrigation) ▪ Effective control of weeds to reduce transpiration from weeds
Enhancing effective use of rainfall	▪ Synchronizing crop scheduling and rainfall ▪ Water harvesting and supplemental irrigation

Sources: Hatfield et al. (2001); Kijne et al. (2007); Sadras et al. (2007); Hoekstra et al. (2011).

The use of fertilizers will often improve water productivity, because yields will increase while water consumption can remain more or less equal. However, above a certain fertilizer application rate, yields may still slightly increase, but the effect of nutrient leaching and runoff to the freshwater system will start to dominate. When applying fertilizers, the trade-off between higher crop water productivity (smaller green-blue water footprint) and potential pollution of the groundwater and streams through nutrients (grey water footprint) should be considered carefully. Setting a grey water footprint benchmark value as done in this report may help to integrate the issue of water pollution into the discussion on water use efficiency in agriculture, a discussion that is usually fully focused on the consumptive side of freshwater appropriation, leaving out the pollution side.

When applying water footprint benchmark values as target levels, trade-offs may be required when setting specific green, blue and grey water footprint target levels. Particularly, grey water footprints can often be easily reduced by reducing the use of fertilizers and pesticides (and applying the amounts still used in the optimal way at the best time so that yields are not affected), but at some point this may reduce yield and – since the evapotranspiration rate remains equal – thus increase the green-blue water footprint in terms of m^3/ton. A similar thing can happen when reducing the blue water footprint by applying less irrigation water, for instance by deficit precision irrigation using drip technology, since at some point further reduction of irrigation may lower the yield so that the blue water footprint per hectare may still diminish, but the green, blue and grey water footprint per unit of crop will increase.

5. Conclusion

With increasing water scarcity, there is a growing interest in improving crop water productivity in order to meet the growing global food demand with the limited freshwater resources. The challenge is thus to produce more crops with less water, thus reducing the water footprint per unit of crop produced. This study has developed water footprint benchmark values for a large number of crops grown in the world. The study shows that water savings and reduced water pollution can be very substantial – 39% of global water saving and 54% of reduced water pollution – if water footprints per unit of crop are reduced to levels similar to the best quarter of global production. Our estimation of the potential reduction in the global water footprint of crop production is not meant to imply that this reduction is easily attainable. Raising yields in low-income countries will require large investments in capacity building and appropriate technologies.

Water footprint benchmarks for crops as developed in this study can be used to provide an incentive for farmers to reduce the water footprint of their crops towards reasonable levels and thus use water more efficiently. When granting water consumption permits to farmers and developing regulations on fertiliser use, it makes sense for governments to take into account the relevant water footprint benchmarks for the specific crops grown. The benchmarks are equally relevant for the food-processing industry, which increasingly focusses on the efficient and sustainable use of water in their supply chain (e.g. Unilever, 2012; Sikirica, 2011; TCCC and TNC, 2010). The same holds for the apparel sector, particularly regarding cotton (Franke and Mathews, 2013), for the cosmetics industry, which uses various sorts of agricultural inputs (Francke and Castro, 2013), and the biofuel sector (Gerbens-Leenes et al. 2009). Water footprint benchmarks will enable the actors along supply chains – from farmers through intermediate companies to final consumers – to compare the actual water footprint of products against certain reference levels. The benchmark values can be used to measure performance, to set water footprint reduction targets and monitor progress in achieving these targets.

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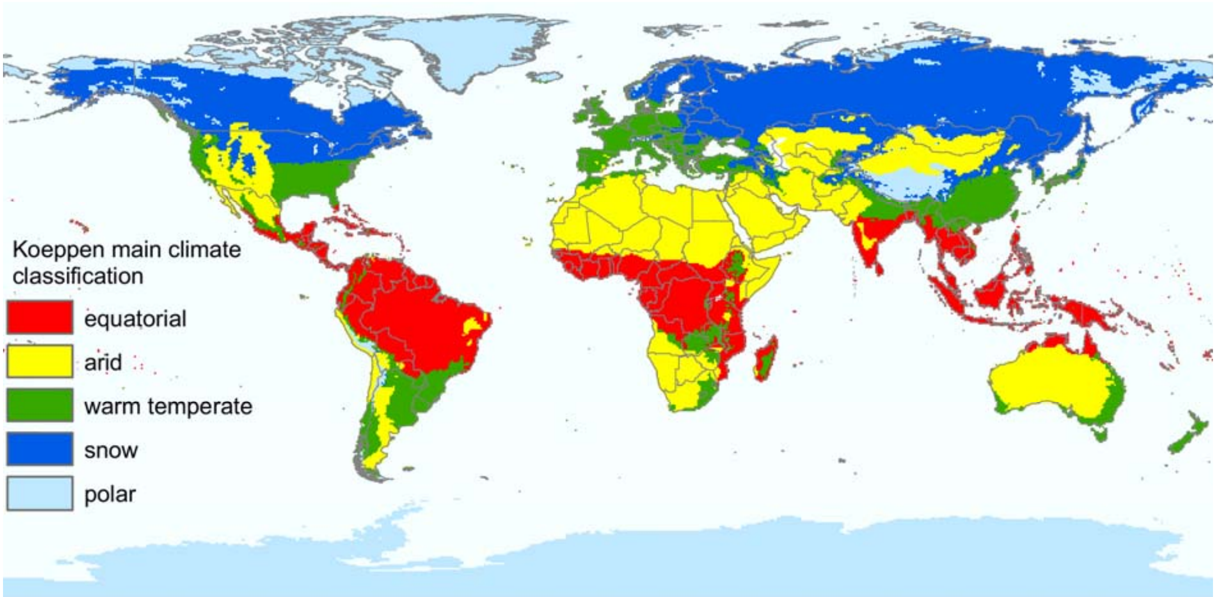
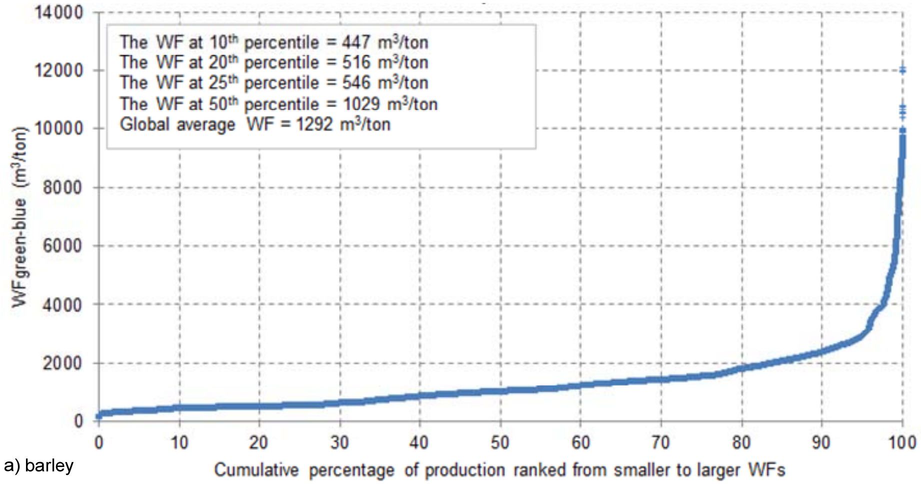
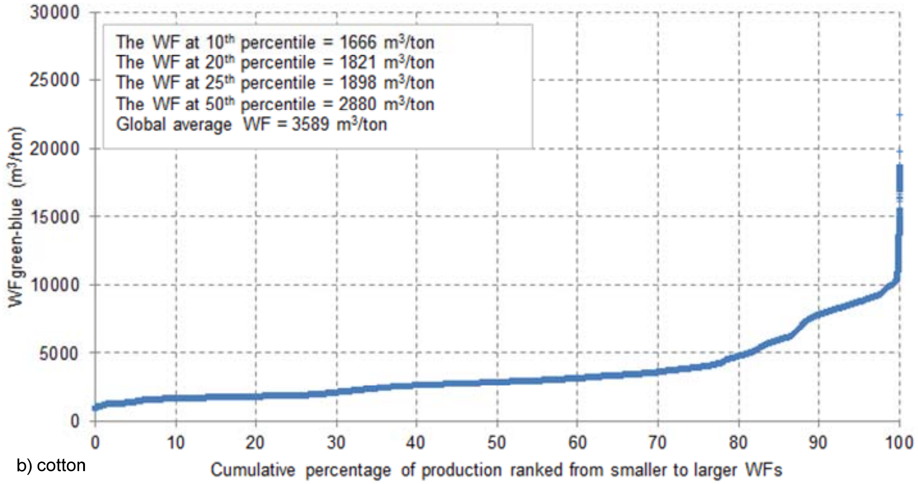
Appendix I: World map of the Köppen-Geiger climate classification



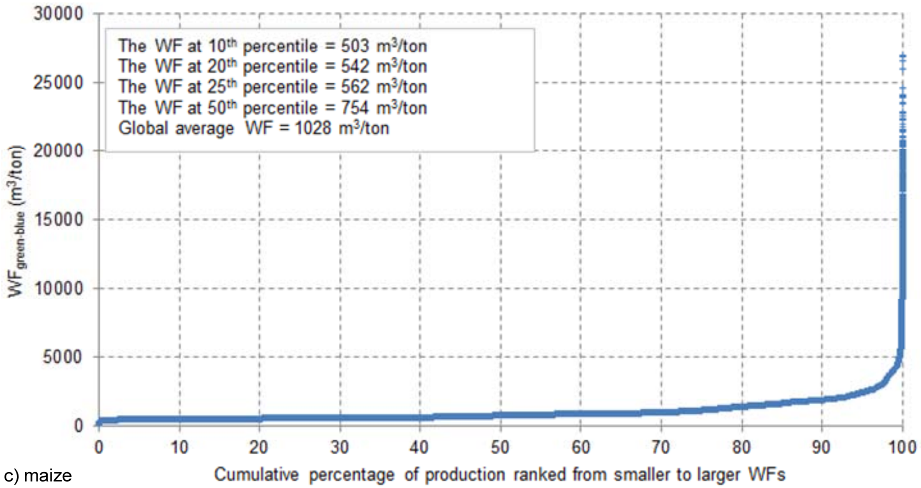
Appendix II: Green-blue water footprint of selected crops for all crop producing grid cells in the world, plotted from smallest to largest WF



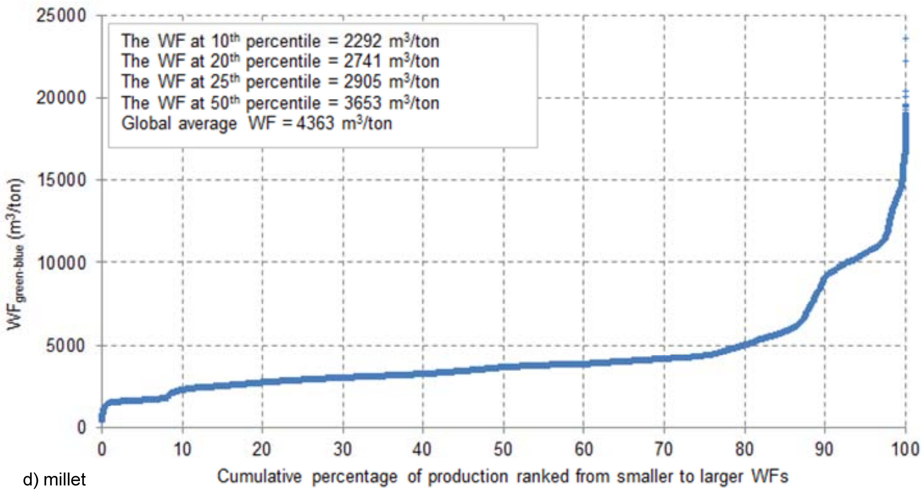
a) barley



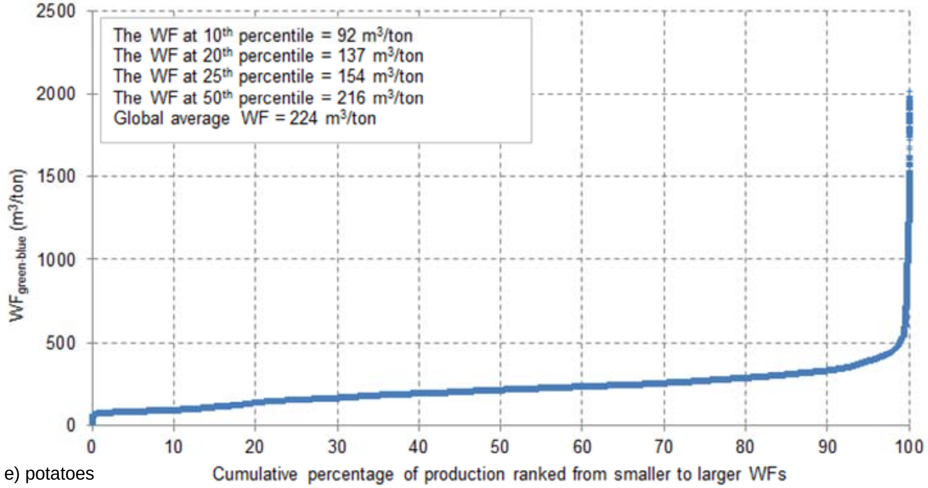
b) cotton



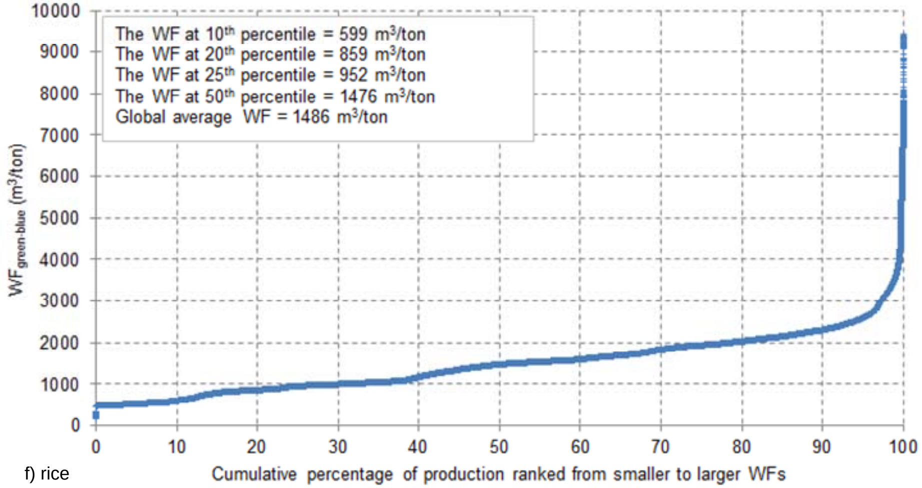
c) maize



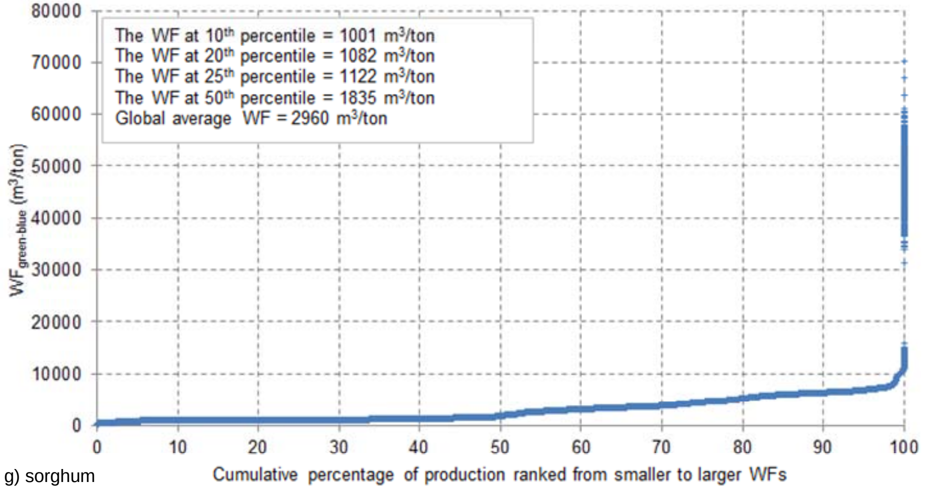
d) millet



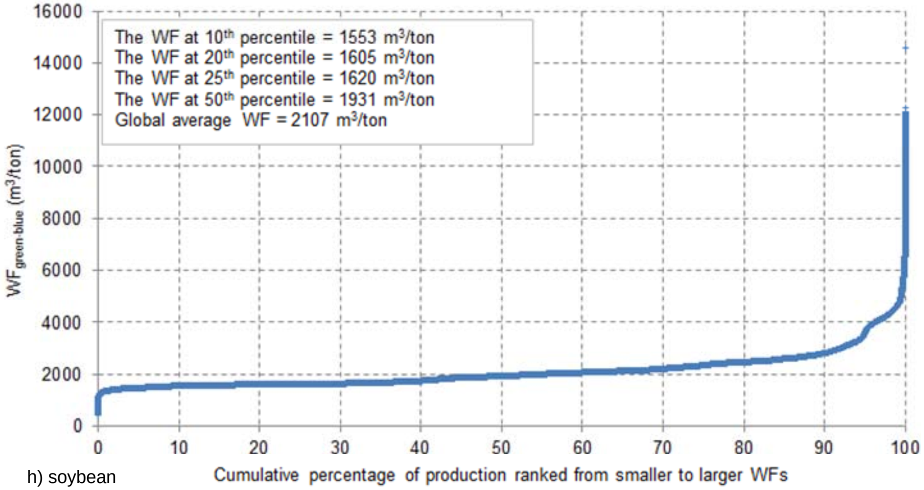
e) potatoes



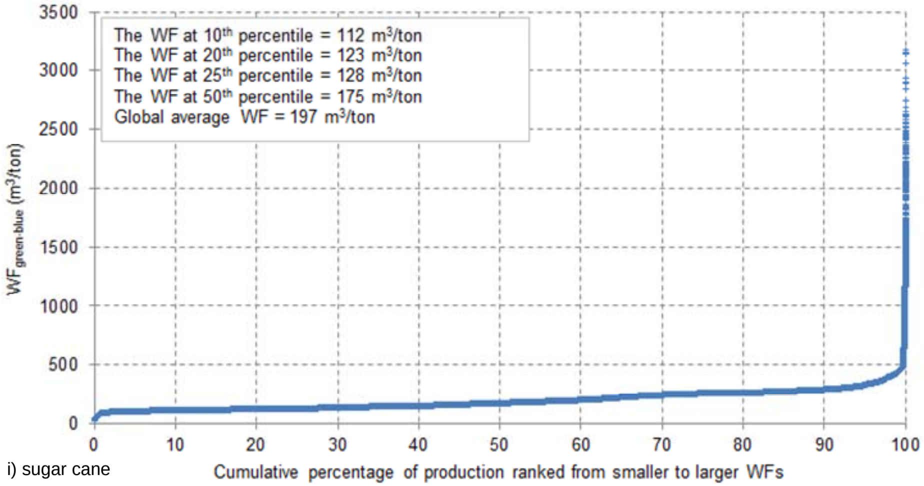
f) rice



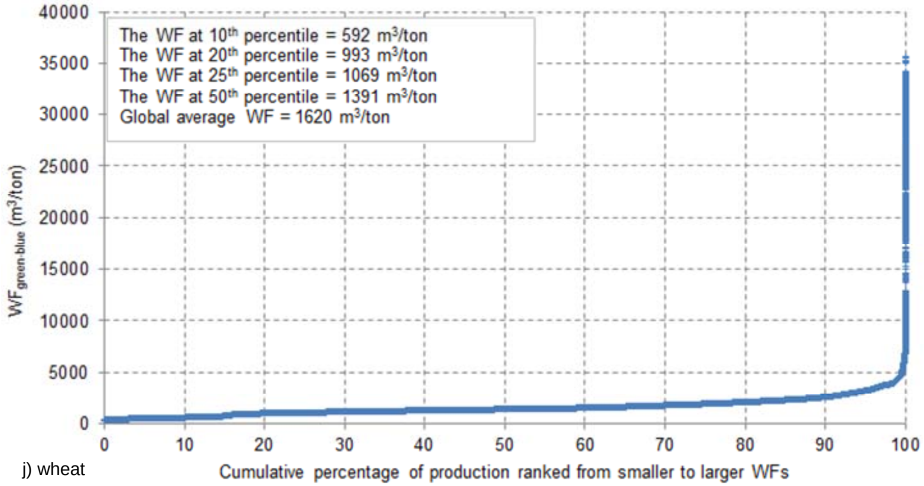
g) sorghum



h) soybean



i) sugar cane



j) wheat

Appendix III: Green-blue water footprint at different production percentiles

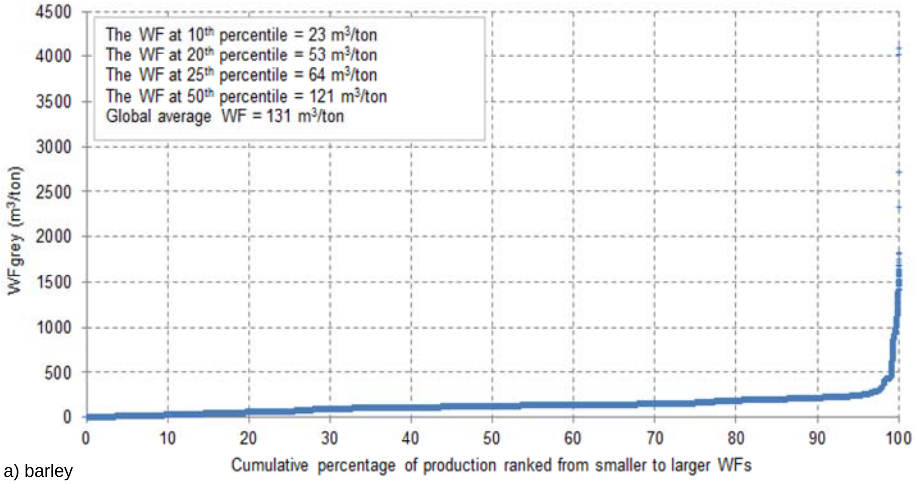
Crop code	Crop	Green-blue water footprint (m^3/ton) at different production percentiles				Global average
		10th	20th	25th	50th	
15	Wheat	592	993	1069	1391	1620
27	Rice, paddy	599	859	952	1476	1486
44	Barley	447	516	546	1029	1292
56	Maize	503	542	562	754	1028
71	Rye	356	398	562	1400	1445
75	Oats	561	674	830	1474	1660
79	Millet	2292	2741	2905	3653	4363
83	Sorghum	1001	1082	1122	1835	2960
89	Buckwheat	1621	1903	2014	2182	2913
97	Triticale	512	534	545	910	866
103	Mixed grain	1153	1482	1615	1714	1633
108	Cereals, not elsewhere specified	2746	3006	3091	3557	3432
116	Potatoes	92	137	154	216	224
122	Sweet potatoes	203	219	224	249	330
125	Cassava	367	401	367	504	550
136	Taro (coco yam)	255	354	473	528	591
137	Yams	279	294	298	324	342
149	Roots and tubers, not elsewhere specified	148	264	279	337	363
156	Sugarcane	112	123	128	175	197
157	Sugar beets	46	58	62	93	108
176	Beans, dry	1390	1748	1865	3205	4070
181	Broad beans, dry	738	916	960	1331	1521
187	Peas, dry	503	586	688	1241	1486
191	Chickpeas	1926	2251	2410	2979	3196
195	Cowpeas, dry	3149	4212	4340	4731	6850
197	Pigeon peas	3058	3845	4030	4567	4811
201	Lentils	1856	2060	2145	2915	4814
205	Vetches	721	1233	1332	1757	2140
210	Lupins	957	1174	1204	1339	1371
211	Pulses, not elsewhere specified	610	1061	1149	1868	2467
217	Cashew nuts	4221	4579	4702	6290	13774
220	Chestnuts	1220	1292	1332	1524	2606
221	Almonds	1881	2207	2390	4025	6540
222	Walnuts	1813	2503	2830	3868	4105
223	Pistachios	2658	3350	3677	10920	10697
225	Hazelnuts (filberts)	3753	3938	4014	4421	4903
234	Nuts, not elsewhere specified	2412	3000	3383	5822	9535

Crop code	Crop	Green-blue water footprint (m^3/ton) at different production percentiles				Global average
		10th	20th	25th	50th	
236	Soybeans	1553	1605	1620	1931	2107
242	Groundnuts in shell	1382	1459	1507	2269	2618
249	Coconuts	1733	2159	2234	2682	2671
254	Oil palm fruit	661	696	707	896	1057
260	Olives	1560	1776	1866	2515	2969
265	Castor beans	7379	7942	8090	8891	9598
267	Sunflower seed	1780	2329	2512	2945	3165
270	Rapeseed	1050	1158	1204	1505	1935
280	Safflower seed	2177	2593	3169	5183	6938
289	Sesame seed	4127	4479	4686	8095	8969
292	Mustard seed	1913	2032	2079	2264	2464
299	Melonseed	3067	3784	4441	5155	5143
328	Seed cotton	1666	1822	1898	2880	3589
333	Linseed	2608	2722	2760	3338	5005
358	Cabbages	91	128	148	218	208
366	Artichokes	440	481	505	640	720
367	Asparagus	1362	1457	1491	1661	1643
372	Lettuce	57	92	109	160	161
373	Spinach	92	97	99	113	132
388	Tomatoes	63	89	98	156	171
393	Cauliflower	161	173	178	202	211
394	Pumpkins, squash, gourds	118	152	164	207	252
397	Cucumbers and gherkins	93	184	198	243	249
399	Eggplants	181	210	217	245	267
401	Chillies and peppers, green	115	169	180	221	282
402	Onions and shallots, green	84	139	155	208	221
403	Onions, dry	107	164	187	229	280
406	Garlic	265	277	284	315	419
414	Beans, green	178	194	202	266	374
417	Peas, green	218	306	323	378	446
423	String beans	225	252	277	397	405
426	Carrots	56	67	78	121	134
430	Okra	280	307	313	351	511
446	Green corn (maize)	288	347	371	466	612
463	Vegetables Fresh, not elsewhere specified	147	176	186	221	237
486	Bananas	321	373	397	550	756
489	Plantains	1004	1178	1225	1453	1597
490	Oranges	303	333	343	383	510
495	Tangerine, mandarin, clementine,	319	421	449	608	597

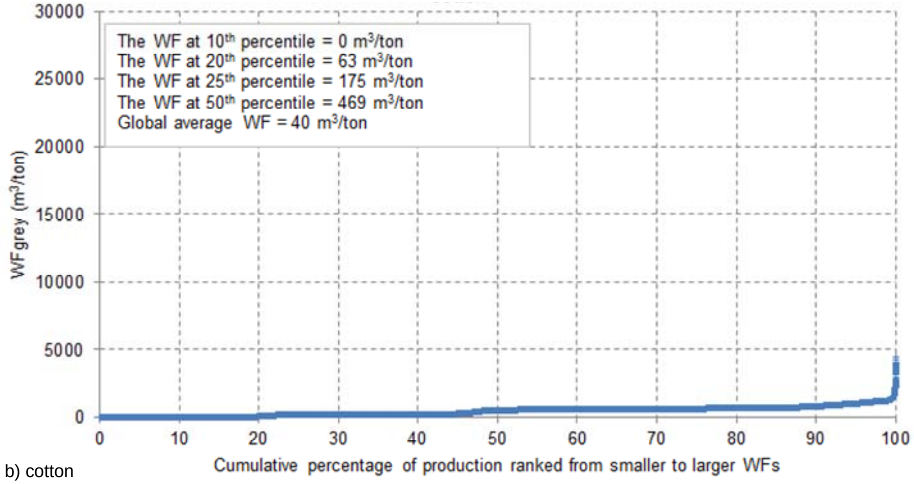
Crop code	Crop	Green-blue water footprint (m^3/ton) at different production percentiles				Global average
		10th	20th	25th	50th	
	satsma					
497	Lemons and limes	260	324	342	497	584
507	Grapefruit and pomelos	172	191	275	316	453
512	Citrus fruit, not elsewhere specified	407	506	534	1330	1207
515	Apples	206	282	341	697	695
521	Pears	247	392	427	793	739
526	Apricots	607	682	720	1032	1195
530	Sour cherries	652	719	782	1251	1312
531	Cherries	601	793	1045	1458	1493
534	Peaches and nectarines	358	426	465	738	770
536	Plums	614	864	972	1857	1758
541	Stone fruit fresh, not elsewhere specified	852	1008	1126	1806	1916
544	Strawberries	99	115	123	179	311
547	Raspberries	188	217	230	281	346
549	Gooseberries	386	400	408	430	495
550	Currants	318	338	349	463	477
552	Blueberries	274	377	402	592	675
554	Cranberries	141	152	156	181	199
558	Berries, not elsewhere specified	226	246	256	365	376
560	Grapes	285	331	356	443	522
567	Watermelons	115	126	129	144	175
568	Cantaloupes and other melons	100	112	116	136	154
569	Figs	1199	1464	1518	1711	3049
571	Mangoes	904	1116	1198	1673	1676
572	Avocados	716	820	853	974	1087
574	Pineapples	93	122	133	167	224
577	Dates	91	465	474	2200	2180
592	Kiwi Fruit	308	329	348	426	475
603	Tropical fruit, fresh, not elsewhere specified	1105	1188	1225	1419	1656
619	Fruit, fresh, not elsewhere specified	119	318	420	836	1400
656	Coffee, green	7885	9960	10463	11716	15365
661	Cocoa beans	12931	13782	14248	19768	19749
667	Tea	3853	5185	5572	7638	8130
677	Hops	1550	1816	1865	2047	2655
687	Pepper, white/long/black	1638	2200	2359	4998	7007
689	Pimento, allspice	1153	2641	4775	6678	6994
692	Vanilla	18370	47475	49749	58443	125440
702	Nutmeg, mace, cardamoms	18908	23267	25492	29314	33306

Crop code	Crop	Green-blue water footprint (m^3/ton) at different production percentiles				Global average
		10th	20th	25th	50th	
711	Anise, badian, fennel	742	2570	2998	5707	7235
720	Ginger	306	362	397	732	1565
723	Spices, not elsewhere specified	1404	2129	2320	2777	2977
773	Flax fibre and tow	1130	1206	1252	1451	3109
780	Jute	2197	2228	2241	2327	2389
782	Jute-like fibres	1420	1553	1627	4353	3693
789	Sisal	5000	5844	6129	6790	6820
821	Fibre crops, not elsewhere specified	885	965	1002	2710	5938
826	Tobacco leaves	1084	1608	1710	2146	2226
836	Natural rubber	6579	6904	7395	9380	13325
900a	Fodder crops	138	152	159	207	233

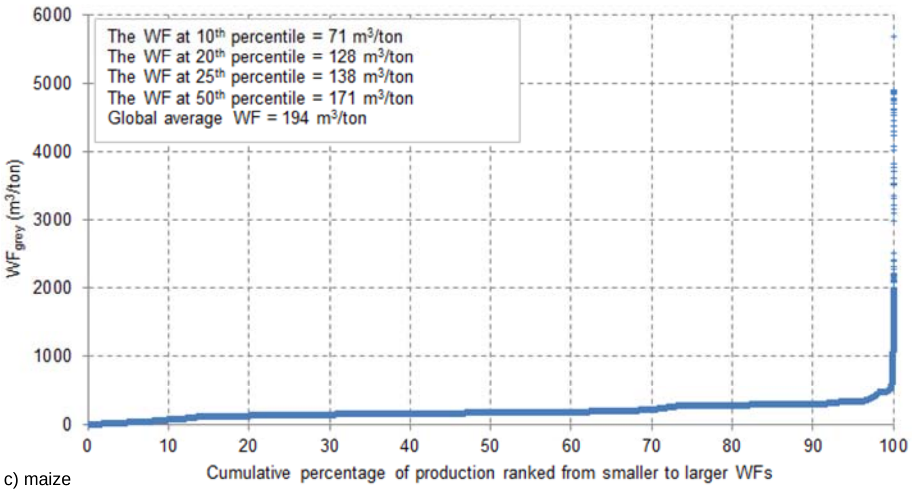
Appendix IV: Grey water footprint of selected crops for all crop producing grid cells in the world, plotted from smallest to largest WF



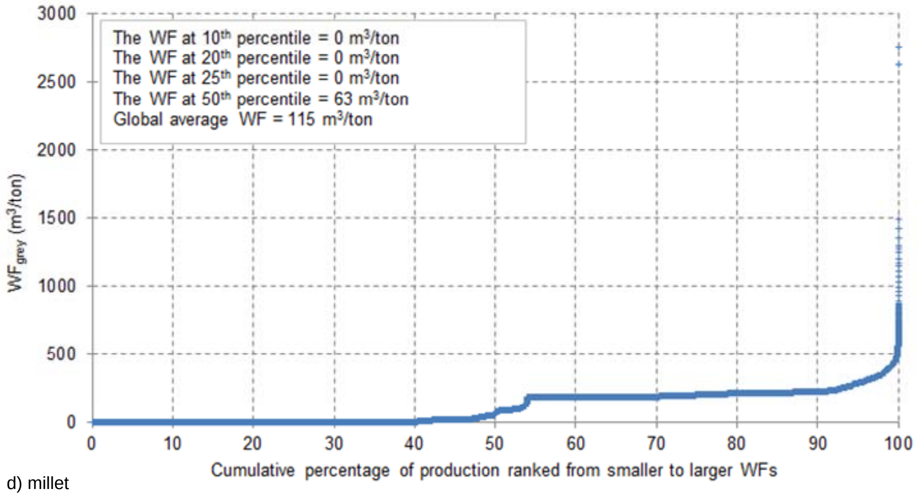
a) barley



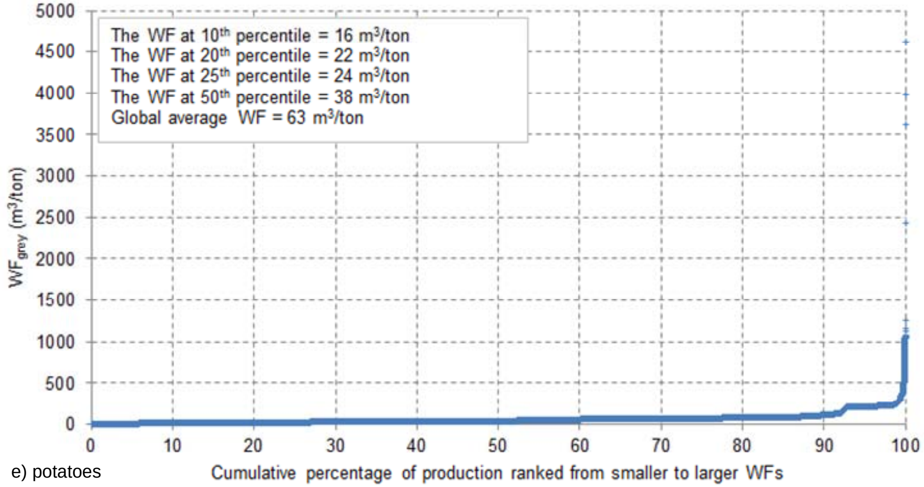
b) cotton



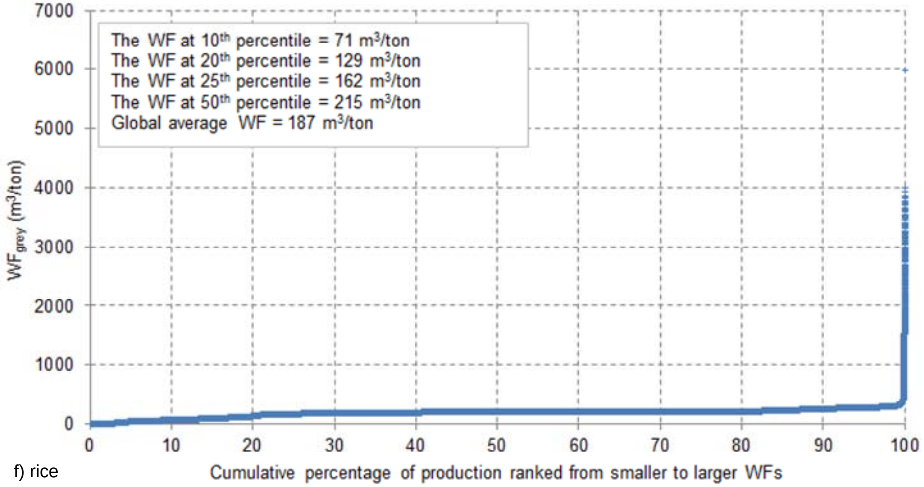
c) maize



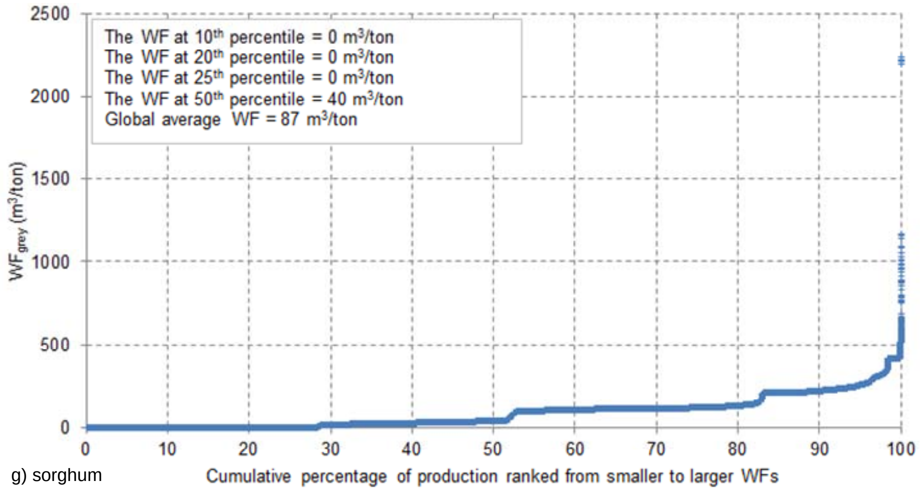
d) millet



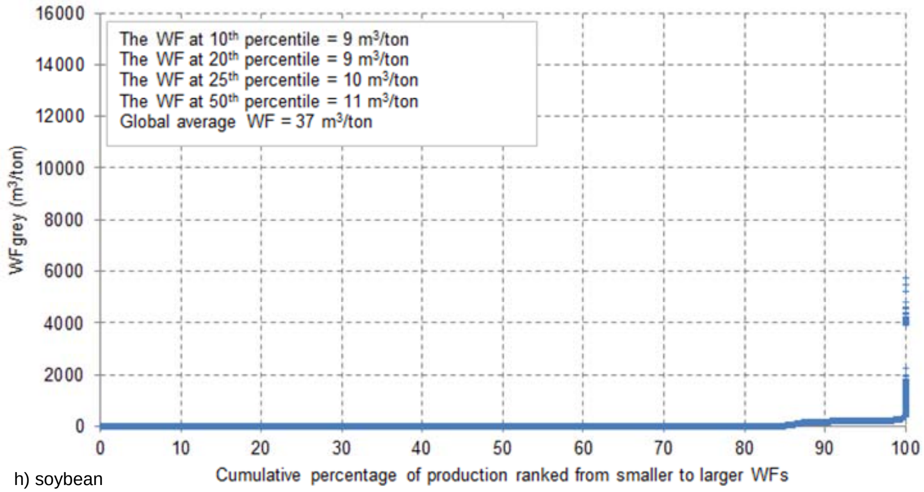
e) potatoes



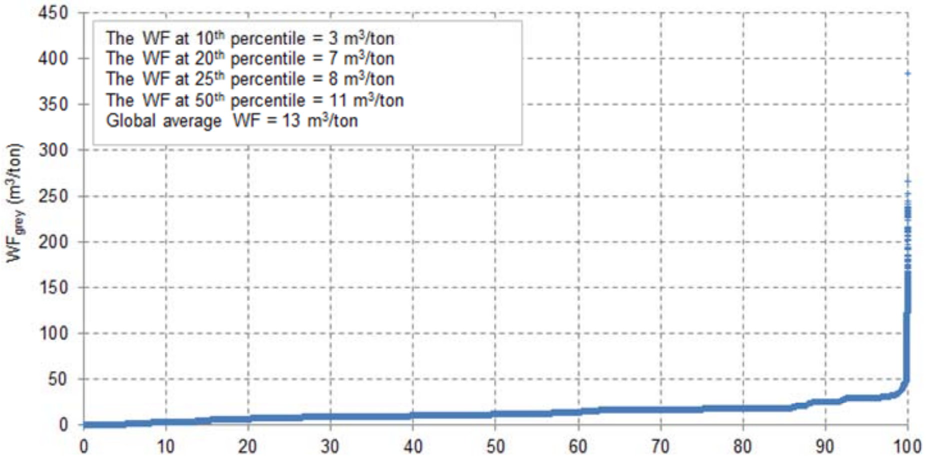
f) rice



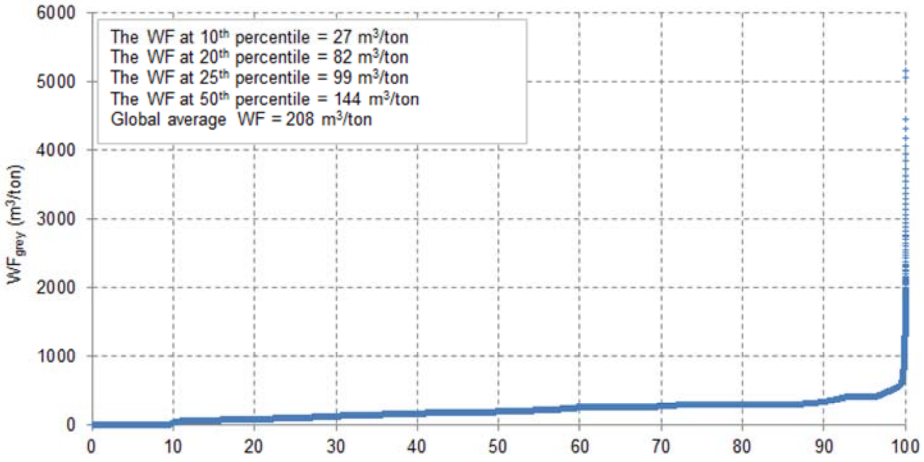
g) sorghum



h) soybean



i) sugar cane



j) wheat

Appendix V: Grey water footprint at different production percentiles

Crop code	Crop	Grey water footprint (m^3/ton) at different production percentiles				Global average
		10th	20th	25th	50th	
15	Wheat	27	82	99	144	208
27	Rice, paddy	71	129	162	215	187
44	Barley	23	53	64	121	131
56	Maize	71	128	138	171	194
71	Rye	0	0	7	61	99
75	Oats	22	44	56	114	128
79	Millet	0	0	0	63	115
83	Sorghum	0	0	0	40	87
89	Buckwheat	55	128	136	265	229
97	Triticale	0	0	0	100	89
103	Mixed grain	0	0	0	0	28
108	Cereals, not elsewhere specified	0	0	0	0	9
116	Potatoes	16	22	24	38	63
122	Sweet potatoes	14	50	50	50	53
125	Cassava	0	0	1	3	13
136	Taro (coco yam)	1	1	1	1	15
137	Yams	0	1	1	1	1
149	Roots and tubers, not elsewhere specified	0	0	0	0	22
156	Sugarcane	3	7	8	11	13
157	Sugar beets	7	10	11	17	25
176	Beans, dry	0	1	7	373	983
181	Broad beans, dry	0	0	0	442	496
187	Peas, dry	0	0	0	227	493
191	Chickpeas	236	575	612	698	981
195	Cowpeas, dry	0	12	12	12	55
197	Pigeon peas	0	3	777	787	683
201	Lentils	153	240	340	846	1060
205	Vetches	0	0	20	158	213
210	Lupins	420	420	420	429	506
211	Pulses, not elsewhere specified	0	13	16	287	650
217	Cashew nuts	3	4	5	231	444
220	Chestnuts	0	0	11	166	144
221	Almonds	0	0	0	770	1507
222	Walnuts	0	0	9	284	814
223	Pistachios	38	268	317	997	666
225	Hazelnuts (filberts)	18	23	178	203	354
234	Nuts, not elsewhere specified	0	0	0	0	891

Crop code	Crop	Grey water footprint (m^3/ton) at different production percentiles				Global average
		10th	20th	25th	50th	
236	Soybeans	9	9	10	11	37
242	Groundnuts in shell	4	9	28	187	163
249	Coconuts	4	5	5	9	16
254	Oil palm fruit	1	33	33	34	40
260	Olives	0	3	3	4	45
265	Castor beans	45	140	150	208	298
267	Sunflower seed	24	28	33	77	201
270	Rapeseed	174	191	212	332	336
280	Safflower seed	37	40	55	345	283
289	Sesame seed	0	0	0	527	403
292	Mustard seed	22	78	97	128	345
299	Melonseed	0	0	0	0	41
328	Seed cotton	0	63	175	469	440
333	Linseed	0	0	0	0	170
358	Cabbages	2	18	24	55	73
366	Artichokes	30	59	61	76	98
367	Asparagus	348	487	487	497	507
372	Lettuce	21	29	33	78	77
373	Spinach	74	130	131	139	160
388	Tomatoes	5	12	13	23	43
393	Cauliflower	33	38	39	63	75
394	Pumpkins, squash, gourds	4	31	36	66	84
397	Cucumbers and gherkins	11	25	36	136	105
399	Eggplants	37	40	41	122	95
401	Chillies and peppers, green	11	24	37	114	97
402	Onions and shallots, green	0	2	11	57	51
403	Onions, dry	6	20	22	36	65
406	Garlic	63	123	125	134	170
414	Beans, green	60	76	91	187	188
417	Peas, green	56	68	69	94	151
423	String beans	64	78	81	152	143
426	Carrots	2	11	15	35	61
430	Okra	0	33	62	66	65
446	Green corn (maize)	0	20	45	86	88
463	Vegetables Fresh, not elsewhere specified	13	31	40	119	101
486	Bananas	0	0	1	19	33
489	Plantains	0	0	0	1	6
490	Oranges	14	15	16	42	49
495	Tangerine, mandarin, clementine,	15	25	39	83	152

Crop code	Crop	Grey water footprint (m^3/ton) at different production percentiles				Global average
		10th	20th	25th	50th	
	satsma					
497	Lemons and limes	14	19	25	49	58
507	Grapefruit and pomelos	0	16	20	39	54
512	Citrus fruit, not elsewhere specified	0	0	0	0	35
515	Apples	3	11	18	54	127
521	Pears	5	27	39	260	183
526	Apricots	11	24	33	80	92
530	Sour cherries	0	2	13	78	99
531	Cherries	10	23	27	82	112
534	Peaches and nectarines	32	47	48	80	139
536	Plums	19	37	57	149	422
541	Stone fruit fresh, not elsewhere specified	17	30	36	133	136
544	Strawberries	5	9	11	27	37
547	Raspberries	0	6	7	44	67
549	Gooseberries	0	2	7	34	31
550	Currants	0	0	0	7	23
552	Blueberries	0	182	182	212	170
554	Cranberries	25	80	81	82	77
558	Berries, not elsewhere specified	17	25	26	89	74
560	Grapes	13	20	31	81	87
567	Watermelons	19	34	43	73	63
568	Cantaloupes and other melons	12	34	37	64	67
569	Figs	46	154	170	171	227
571	Mangoes	0	62	76	93	124
572	Avocados	0	1	8	92	87
574	Pineapples	0	0	2	13	31
577	Dates	21	59	69	92	98
592	Kiwi Fruit	0	0	0	41	38
603	Tropical fruit, fresh, not elsewhere specified	31	49	52	70	172
619	Fruit, fresh, not elsewhere specified	0	3	3	32	112
656	Coffee, green	20	206	234	281	532
661	Cocoa beans	17	19	19	22	179
667	Tea	76	163	227	357	726
677	Hops	0	0	0	0	1414
687	Pepper, white/long/black	5	88	99	265	604
689	Pimento, allspice	0	38	111	331	371
692	Vanilla	0	0	0	1312	1065
702	Nutmeg, mace, cardamoms	0	0	0	331	1014

Crop code	Crop	Grey water footprint (m^3/ton) at different production percentiles				Global average
		10th	20th	25th	50th	
711	Anise, badian, fennel	0	32	35	1009	1046
720	Ginger	10	15	18	76	92
723	Spices, not elsewhere specified	57	275	287	325	390
773	Flax fibre and tow	0	0	3	310	401
780	Jute	66	67	67	276	217
782	Jute-like fibres	97	291	312	340	500
789	Sisal	0	0	23	241	222
821	Fibre crops, not elsewhere specified	0	69	69	69	270
826	Tobacco leaves	11	116	135	610	700
836	Natural rubber	269	302	309	391	422
900a	Fodder crops	4	5	6	15	20

Appendix VI: Potential global green-blue water savings in crop production

Crop code	Crop	Global total green-blue water footprint (billion m^3/yr)	Global green-blue water saving (%) if everywhere the water footprint of crop production is reduced to the level of the best x^{th} percentile of current global production			
			10^{th}	20th	25^{th}	50^{th}
15	Wheat	964	64	43	39	25
27	Rice, paddy	881	60	44	40	18
44	Barley	184	66	61	60	36
56	Maize	648	51	48	46	35
71	Rye	29.2	76	73	65	24
75	Oats	44.7	67	61	54	30
79	Millet	126	49	39	36	25
83	Sorghum	177	67	64	63	50
89	Buckwheat	8.15	45	36	33	30
97	Triticale	8.82	41	38	38	14
103	Mixed grain	8.33	30	13	7	2
108	Cereals, not elsewhere specified	8.89	25	19	17	5
116	Potatoes	70.4	59	42	36	17
122	Sweet potatoes	44.2	39	34	32	26
125	Cassava	99.0	34	28	34	16
136	Taro (coco yam)	5.62	57	43	27	22
137	Yams	13.9	20	16	15	9
149	Roots and tubers, not elsewhere specified	2.53	60	33	30	18
156	Sugarcane	254	43	38	35	21
157	Sugar beets	27.1	57	48	45	27
176	Beans, dry	72.9	66	58	56	35
181	Broad beans, dry	6.03	53	42	40	21
187	Peas, dry	16.3	66	62	56	31
191	Chickpeas	26.2	41	32	28	13
195	Cowpeas, dry	25.4	55	42	40	35
197	Pigeon peas	14.6	39	25	22	13
201	Lentils	15.1	62	58	57	47
205	Vetches	2.40	68	48	44	30
210	Lupins	2.10	31	16	14	5
211	Pulses, not elsewhere specified	8.73	76	60	57	37
217	Cashew nuts	27.6	70	67	66	60
220	Chestnuts	2.57	53	50	49	45
221	Almonds	10.3	72	67	65	48
222	Walnuts	5.57	58	43	36	19
223	Pistachios	4.93	75	69	67	32

Crop code	Crop	Global total green-blue water footprint (billion m^3/yr)	Global green-blue water saving (%) if everywhere the water footprint of crop production is reduced to the level of the best x^{th} percentile of current global production			
			10^{th}	20th	25^{th}	50^{th}
225	Hazelnuts (filberts)	3.59	24	20	18	10
234	Nuts, not elsewhere specified	6.14	75	70	66	51
236	Soybeans	363	26	24	23	15
242	Groundnuts in shell	89.3	47	45	43	27
249	Coconuts	139	36	22	20	9
254	Oil palm fruit	136	38	35	34	21
260	Olives	47.0	48	42	39	25
265	Castor beans	11.8	23	18	17	10
267	Sunflower seed	81.6	45	30	26	17
270	Rapeseed	75.0	46	41	39	29
280	Safflower seed	4.76	69	64	58	40
289	Sesame seed	26.1	54	51	49	25
292	Mustard seed	1.40	24	20	18	14
299	Melonseed	3.13	42	30	20	9
328	Seed cotton	207	54	50	49	30
333	Linseed	11.5	48	46	46	39
358	Cabbages	12.0	56	41	34	12
366	Artichokes	0.91	39	34	32	19
367	Asparagus	8.04	18	13	11	2
372	Lettuce	2.99	65	46	38	18
373	Spinach	1.28	31	27	26	16
388	Tomatoes	18.7	64	50	46	26
393	Cauliflower	3.17	25	19	17	9
394	Pumpkins, squash, gourds	4.53	54	42	38	27
397	Cucumbers and gherkins	8.67	64	33	28	14
399	Eggplants	7.06	34	24	22	13
401	Chillies and peppers, green	5.94	61	44	41	30
402	Onions and shallots, green	0.71	62	41	35	19
403	Onions, dry	14.2	62	45	39	28
406	Garlic	4.80	37	34	32	25
414	Beans, green	2.15	53	49	47	36
417	Peas, green	3.43	52	35	31	22
423	String beans	0.73	45	40	35	14
426	Carrots	2.92	59	52	45	25
430	Okra	2.71	46	41	40	34
446	Green corn (maize)	5.42	53	45	41	30
463	Vegetables Fresh, not elsewhere specified	50.0	39	28	24	13

Crop code	Crop	Global total green-blue water footprint (billion m^3/yr)	Global green-blue water saving (%) if everywhere the water footprint of crop production is reduced to the level of the best x^{th} percentile of current global production			
			10^{th}	20th	25^{th}	50^{th}
486	Bananas	50.7	58	52	49	36
489	Plantains	50.4	38	29	27	17
490	Oranges	31.8	41	37	35	30
495	Tangerine, mandarin, clementine, satsma	12.1	47	32	29	12
497	Lemons and limes	6.46	56	47	44	27
507	Grapefruit and pomelos	2.25	62	58	42	38
512	Citrus fruit, not elsewhere specified	7.71	67	60	58	16
515	Apples	40.6	71	61	55	24
521	Pears	12.0	67	50	46	13
526	Apricots	3.31	50	44	41	26
530	Sour cherries	1.44	50	46	42	19
531	Cherries	2.63	60	49	36	17
534	Peaches and nectarines	10.7	54	46	42	20
536	Plums	15.2	66	53	48	17
541	Stone fruit fresh, not elsewhere specified	0.81	56	49	45	22
544	Strawberries	1.00	68	63	61	48
547	Raspberries	0.14	46	37	34	22
549	Gooseberries	0.09	23	20	18	15
550	Currants	0.35	35	31	29	11
552	Blueberries	0.14	60	47	44	24
554	Cranberries	0.06	30	24	22	11
558	Berries, not elsewhere specified	0.24	50	46	44	29
560	Grapes	32.4	46	38	35	25
567	Watermelons	13.2	35	28	27	20
568	Cantaloupes and other melons	3.30	36	28	26	18
569	Figs	3.31	62	55	54	50
571	Mangoes	43.4	47	36	32	13
572	Avocados	3.02	35	27	24	16
574	Pineapples	3.39	59	48	44	35
577	Dates	13.5	96	81	81	37
592	Kiwi Fruit	0.47	35	31	27	17
603	Tropical fruit, fresh, not elsewhere specified	22.7	34	29	27	20
619	Fruit, fresh, not elsewhere specified	32.5	92	77	70	41
656	Coffee, green	108	50	38	35	29
661	Cocoa beans	67.0	37	33	31	15

Crop code	Crop	Global total green-blue water footprint (billion m^3/yr)	Global green-blue water saving (%) if everywhere the water footprint of crop production is reduced to the level of the best x^{th} percentile of current global production			
			10^{th}	20th	25^{th}	50^{th}
667	Tea	25.2	53	39	35	20
677	Hops	0.33	42	32	31	27
687	Pepper, white/long/black	2.34	77	70	69	47
689	Pimento, allspice	16.8	84	66	42	23
692	Vanilla	0.62	86	67	65	60
702	Nutmeg, mace, cardamoms	2.46	45	34	28	19
711	Anise, badian, fennel	2.61	90	68	63	41
720	Ginger	1.55	81	78	76	63
723	Spices, not elsewhere specified	3.57	54	33	28	16
773	Flax fibre and tow	2.01	63	61	59	56
780	Jute	6.69	9	8	7	5
782	Jute-like fibres	1.60	62	59	57	9
789	Sisal	2.19	31	20	17	9
821	Fibre crops, not elsewhere specified	1.70	91	90	90	81
826	Tobacco leaves	15.3	53	33	29	15
836	Natural rubber	100	51	49	45	37
900a	Fodder crops	631	41	36	33	20
	Total	6625	52	42	39	25

Appendix VII: Potential global water pollution reduction in crop production

Crop code	Crop	Global total grey water footprint (billion m³/yr)	Global reduction in water pollution (%) if everywhere the grey water footprint of crop production is reduced to the level of the best x[th] percentile of current global production			
			10[th]	20th	25[th]	50[th]
15	Wheat	123	88	65	58	43
27	Rice, paddy	111	64	38	24	4
44	Barley	18.7	83	63	57	27
56	Maize	122	65	40	36	23
71	Rye	2.00	100	100	95	57
75	Oats	3.45	84	70	63	36
79	Millet	3.31	100	100	100	70
83	Sorghum	5.21	100	100	100	70
89	Buckwheat	0.64	77	51	48	12
97	Triticale	0.91	100	100	100	38
103	Mixed grain	0.15	100	100	100	100
108	Cereals, not elsewhere specified	0.02	100	100	100	100
116	Potatoes	19.9	76	67	64	50
122	Sweet potatoes	7.13	76	16	16	16
125	Cassava	2.39	100	100	94	84
136	Taro (coco yam)	0.14	95	94	94	94
137	Yams	0.05	63	49	49	49
149	Roots and tubers, not elsewhere specified	0.15	100	100	100	100
156	Sugarcane	16.9	78	52	46	30
157	Sugar beets	6.26	72	62	58	43
176	Beans, dry	17.6	100	100	99	74
181	Broad beans, dry	1.97	100	100	100	38
187	Peas, dry	5.41	100	100	100	72
191	Chickpeas	8.04	78	48	45	38
195	Cowpeas, dry	0.21	100	81	81	81
197	Pigeon peas	2.07	100	100	11	10
201	Lentils	3.32	87	79	72	41
205	Vetches	0.24	100	100	93	51
210	Lupins	0.78	23	23	23	21
211	Pulses, not elsewhere specified	2.30	100	98	98	74
217	Cashew nuts	0.89	99	99	99	67
220	Chestnuts	0.14	100	100	94	19
221	Almonds	2.38	100	100	100	70
222	Walnuts	1.10	100	100	99	78
223	Pistachios	0.31	95	65	59	3

Crop code	Crop	Global total grey water footprint (billion m^3/yr)	Global reduction in water pollution (%) if everywhere the grey water footprint of crop production is reduced to the level of the best xth percentile of current global production			
			10th	20th	25th	50th
225	Hazelnuts (filberts)	0.26	95	94	60	54
234	Nuts, not elsewhere specified	0.57	100	100	100	100
236	Soybeans	6.43	76	76	74	73
242	Groundnuts in shell	5.57	98	95	86	21
249	Coconuts	0.83	77	71	71	56
254	Oil palm fruit	5.18	98	29	29	27
260	Olives	0.72	100	94	94	93
265	Castor beans	0.36	86	58	55	39
267	Sunflower seed	5.18	88	87	85	71
270	Rapeseed	13.0	51	46	41	19
280	Safflower seed	0.19	87	86	82	16
289	Sesame seed	1.17	100	100	100	28
292	Mustard seed	0.20	94	80	76	71
299	Melonseed	0.03	100	100	100	100
328	Seed cotton	25.4	100	88	68	31
333	Linseed	0.39	100	100	100	100
358	Cabbages	4.21	97	78	72	47
366	Artichokes	0.12	71	45	43	32
367	Asparagus	2.48	35	11	11	9
372	Lettuce	1.43	73	63	58	23
373	Spinach	1.55	55	26	25	21
388	Tomatoes	4.65	89	75	73	57
393	Cauliflower	1.12	58	51	50	33
394	Pumpkins, squash, gourds	1.52	96	68	63	40
397	Cucumbers and gherkins	3.64	90	78	70	7
399	Eggplants	2.52	63	60	59	11
401	Chillies and peppers, green	2.05	90	78	67	19
402	Onions and shallots, green	0.16	100	97	82	21
403	Onions, dry	3.33	91	73	70	56
406	Garlic	1.95	65	34	33	29
414	Beans, green	1.08	70	62	55	22
417	Peas, green	1.16	65	58	57	46
423	String beans	0.26	58	49	47	14
426	Carrots	1.33	97	85	80	59
430	Okra	0.35	100	58	23	18
446	Green corn (maize)	0.78	100	81	58	27
463	Vegetables Fresh, not elsewhere specified	21.2	88	72	65	15

Crop code	Crop	Global total grey water footprint (billion m^3/yr)	Global reduction in water pollution (%) if everywhere the grey water footprint of crop production is reduced to the level of the best x^{th} percentile of current global production			
			10^{th}	20th	25^{th}	50^{th}
486	Bananas	2.24	100	100	98	62
489	Plantains	0.19	100	100	100	90
490	Oranges	3.07	73	71	70	40
495	Tangerine, mandarin, clementine, satsma	3.07	91	85	78	60
497	Lemons and limes	0.65	78	70	62	36
507	Grapefruit and pomelos	0.27	100	75	68	45
512	Citrus fruit, not elsewhere specified	0.22	100	100	100	100
515	Apples	7.42	98	92	88	71
521	Pears	2.99	97	87	81	14
526	Apricots	0.25	88	77	70	34
530	Sour cherries	0.11	100	98	90	52
531	Cherries	0.20	92	82	79	46
534	Peaches and nectarines	1.94	78	69	68	54
536	Plums	3.63	96	92	88	74
541	Stone fruit fresh, not elsewhere specified	0.06	89	80	77	27
544	Strawberries	0.12	88	79	74	44
547	Raspberries	0.03	100	93	91	61
549	Gooseberries	0.01	100	95	81	35
550	Currants	0.02	100	100	100	77
552	Blueberries	0.04	100	12	12	3
554	Cranberries	0.02	67	6	6	5
558	Berries, not elsewhere specified	0.05	82	74	73	29
560	Grapes	5.39	86	79	69	31
567	Watermelons	4.79	72	52	41	8
568	Cantaloupes and other melons	1.43	83	54	51	26
569	Figs	0.25	81	43	37	37
571	Mangoes	3.22	100	58	49	39
572	Avocados	0.24	100	99	93	29
574	Pineapples	0.46	100	99	95	71
577	Dates	0.61	80	46	38	24
592	Kiwi Fruit	0.04	100	100	100	31
603	Tropical fruit, fresh, not elsewhere specified	2.36	83	74	72	66
619	Fruit, fresh, not elsewhere specified	2.60	100	98	98	80
656	Coffee, green	3.75	97	68	63	57
661	Cocoa beans	0.61	91	90	90	89

Crop code	Crop	Global total grey water footprint (billion m^3/yr)	Global reduction in water pollution (%) if everywhere the grey water footprint of crop production is reduced to the level of the best x^{th} percentile of current global production			
			10^{th}	20th	25^{th}	50^{th}
667	Tea	2.25	90	80	73	60
677	Hops	0.18	100	100	100	100
687	Pepper, white/long/black	0.20	99	87	86	67
689	Pimento, allspice	0.89	100	92	76	40
692	Vanilla	0.01	100	100	100	13
702	Nutmeg, mace, cardamoms	0.07	100	100	100	83
711	Anise, badian, fennel	0.38	100	97	97	39
720	Ginger	0.09	90	85	82	44
723	Spices, not elsewhere specified	0.47	86	36	33	25
773	Flax fibre and tow	0.26	100	100	99	44
780	Jute	0.61	70	70	70	5
782	Jute-like fibres	0.22	82	50	47	44
789	Sisal	0.07	100	100	92	19
821	Fibre crops, not elsewhere specified	0.08	100	88	88	88
826	Tobacco leaves	4.83	99	86	83	41
836	Natural rubber	3.18	41	34	33	21
900a	Fodder crops	52.8	80	76	71	44
	Total	732	79	61	54	33

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