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Value of Water

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THE WATER FOOTPRINT OF BIO-ENERGY:

GLOBAL WATER USE FOR BIO-ETHANOL, BIODIESEL, HEAT AND ELECTRICITY

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Contents

Summary

This study gives a global overview of the water footprint of energy from biomass. The study considers the main crops that could theoretically be a source of energy. The report provides a detailed overview of crop water requirements and water footprints of the main arable crops that together contribute to 80% of the total global arable production (barley, cassava, maize, potato, rapeseed, rice, rye, sorghum, soybean, sugar beet, sugar cane and wheat). We consider the production in the most important producing countries. For these crops, the study refines the available global assessment of water footprints as reported in Chapagain and Hoekstra (2004) and Hoekstra and Chapagain (2007, 2008) by making more detailed assessments based on crop locations and related weather conditions within countries and by distinguishing between green and blue water. The study also includes jatropha, an energy crop that cannot applied in food production.

For specific crops, differences in climate cause large differences in crop water requirements (mm/growth period) among countries. Climatic factors in combination with agricultural practice determine differences among water footprints (m^3/ton). When yield levels are relatively low, water footprints are high and the other way around. When crops are used for bio-energy, it is more efficient to use the total biomass, including stems and leaves, to generate electricity than to use only a fraction of the crop (its sugar, starch or oil content) to produce bio-fuel. The weighted average water footprint of energy (m^3/GJ) is up to a factor two smaller for electricity than for ethanol or biodiesel. The difference is caused by the fraction of the crop that can be applied. For electricity, the total biomass can be used; for bio-ethanol and biodiesel only the sugar or starch fraction, respectively the oil fraction of the yield, can be used. In general, the water footprint of bio-ethanol is smaller than the water footprint of biodiesel. For the generation of electricity, sugar beet, maize and sugar cane with water footprints of about 50 m^3/GJ are the most favourable crops, followed by barley, rye and rice with water footprints of about 70-80 m^3/GJ. Rapeseed and jatropha, typical energy crops, showing water footprints of about 400 m^3/GJ are the most unfavourable crops. For the production of ethanol, two crops grown in a temperate climate, sugar beet and potato, with water footprints of about 60 and 100 m^3/GJ respectively, are the most favourable crops, followed by a crop typical for a warm climate, sugar cane, showing a water footprint of about 110 m^3/GJ. Values for maize and cassava show the same order of magnitude. With a water footprint of 400 m^3/GJ, sorghum is by far the most unfavourable crop for ethanol production. For the production of biodiesel, soybean and rapeseed, crops that are also grown for food, show the most favourable water footprint of 400 m^3/GJ; jatropha, a crop specifically grown for energy has a less favourable water footprint of about 600 m^3/GJ. All figures provided are based on current productivities in the agricultural and energy sector.

The scientific and international political community promote a shift towards non-fossil energy carriers, such as biomass, to reduce the emission of the greenhouse gas CO_2. This study shows that the production of biomass goes along with large water requirements. Already there are reasons for profound concern in several regions and countries with limited water resources whether food and fibre needs of future generations can be met. If a shift towards a larger contribution of bio-energy to total energy supply takes place, results of this study can be used to select the crops and countries that (under current production conditions) produce bio-energy in the most water efficient way.

1. Introduction

Today, humanity already uses 26 percent of the total terrestrial evapotranspiration and 54 percent of accessible runoff (Postel et al., 1996). In the coming decades, humanity will face important challenges, not only to meet the basic human need for water (Gleick, 1998) but also to ensure that the extraction of water from rivers, streams, lakes and aquifers does not affect freshwater ecosystems to perform their ecological functions (Postel, 2000). For a world population of 9.2 billion, as projected by the United Nations for 2050 (UN, 2007), there are reasons for profound concern in several regions and countries with limited water resources with respect to the question whether food and fibre needs of future generations can be met (Fischer et al., 2001; Postel, 2000; Rockström et al., 2007; UNDP, 2006; Vörösmarty et al., 2000).

The scientific as well as the international political community consider global change often in relation to climate change. It is generally recognised that emissions of greenhouse gasses, such as CO_2 from fossil energy carriers, are responsible for anthropogenic impacts on the climate system. In order to reduce CO_2 emissions, a shift towards renewable energy carriers, such as biomass, is heavily promoted. Other advantages of these renewable energy sources are an increase of energy supply security, resource diversification, and the absence of depletion risks (De Vries et al., 2006). The source of biomass for energy can be crops specifically grown for that purpose, natural vegetation or organic wastes (Minnesma and Hisschemöller, 2003). Many of the crops that are used for bio-energy can also – alternatively, not at the same time – be used as food or feed. Biomass can be burnt to produce heat and electricity, but it can also be used as a basis for the production of bio-ethanol or biodiesel, bio-fuels that can displace fossil energy carriers in motor vehicles (Hughes et al., 2007).

Today, the production of biomass for food and fibre in agriculture requires about 86% of the worldwide freshwater use (Hoekstra and Chapagain, 2007, 2008). In many parts of the world, the use of water for agriculture competes with other uses such as urban supply and industrial activities (Falkenmark, 1989), while the aquatic environment shows signs of degradation and decline (Postel et al., 1996). An increase of demand for food in combination with a shift from fossil energy towards energy from biomass puts additional pressure on freshwater resources. For the future, hardly any new land is available, so all production must come from the natural resource base currently available (FAO, 2003), requiring a process of sustainable intensification by increasing the efficiency of the use of land and water (Fresco, 2006).

Globally, many countries are exploring options to replace gasoline by bio-fuels (Hughes et al., 2007). The EU and the US even have set targets for the replacement. The introduction of bio-energy, however, causes externalities. When agriculture grows crops for energy purposes, it needs additional scarce water resources that cannot be used for food anymore. The large-scale cultivation of biomass for the substitution of fossil fuels influences future water demand (Berndes, 2002). The study of Berndes has already provided indicative numbers for the amount of water needed to provide a unit of bio-energy. The replacement of fossil energy by energy from biomass generates the need for detailed information on the water requirements of this new energy source. A tool that has been developed for the calculation of water needs for consumer products is the concept of the water footprint. This tool has been introduced by Hoekstra and Hung (2002) and has been developed further by

Hoekstra and Chapagain (2007, 2008). Those authors define the water footprint as the total annual volume of freshwater used to produce the goods and services related to consumption. So far, the tool has been used to assess the water footprint of food and cotton consumption (Hoekstra and Chapagain, 2007, 2008), as well as for the calculation of the water footprint of primary energy carriers (Gerbens-Leenes et al., 2008).

The objective of this report is to give a global overview of the water footprint per unit of energy (in m^3/GJ) for the various forms of energy that can be derived from biomass. The report not only quantifies the water footprint of heat and electricity from biomass, but also the water footprint of bio-ethanol and biodiesel. The study covers the twelve main crops that together contribute to 80% of total crop production in the world. In addition, the study includes jatropha, a plant species often mentioned in the context of bio-energy. Research questions are: (i) What is the crop water requirement per crop per country and what are the irrigation requirements? (ii) What are the green and blue water footprints in m^3/ton per crop per country? (iii) What are the water footprints in m^3/GJ for heat and electricity derived from the combustion of biomass and (iv) What are the water footprints in m^3/GJ for bio-ethanol and biodiesel? The report does not include an analysis of the water footprint of organic wastes such as manure or crop residues. It also does not consider the water footprint of biogas or the water footprint of energy from algae.

The study builds on two earlier studies: the water footprints of nations (Hoekstra and Chapagain, 2007, 2008) and the water footprint of bio-energy and other primary energy carriers (Gerbens-Leenes et al., 2008). It refines the study of Hoekstra and Chapagain by taking precise national production locations into account for the calculation of the crop water requirements and by using better estimates for the start of the growing season based on an analysis of when the weather conditions at the specific location are most favourable. An additional refinement is that the study differentiates between blue and green water. The study refines the study of Gerbens-Leenes et al. (2008) by extending the research to secondary energy carriers (bio-electricity and bio-fuels).

2. Method

2.1 Different forms of energy from biomass

Energy exists in diverse forms, such as kinetic energy, chemical energy, electricity or heat. Among these various forms, conversions occur. Energy analysis considers a substance an ‘energy carrier’ if the substance is predominantly used as a source of energy (Blok, 2006). Before energy is available in an applicable form for human utilization, for example in the form of power or fuel, energy passes a number of stages in a supply chain. Primary energy carriers are defined as carriers directly derived from a natural source without any conversion process, while secondary energy carriers are the product of a conversion (Blok, 2006). Examples of primary energy carriers are crude oil, coal, natural gas, uranium, hydropower, wind, solar energy, and biomass. Examples of secondary energy carriers are electricity, petrol, biodiesel and ethanol.

Biomass can provide different forms of energy as shown in Figure 1.1. In agriculture crops are grown to provide a yield that has an economic value when applied for food, feed, fibre, or energy production. The term ‘crop yield’ generally refers to the part of the biomass that is harvested in order to be used for food, feed or fibre. For the production of heat or electricity, however, one can apply the total biomass yield, which is more than what is called the ‘crop yield’. The ratio of the crop yield to the total biomass yield is termed the harvest index and shows large differences among crops (Goudriaan et al., 2001). Total biomass yield can be converted into heat and subsequently into electricity. Alternatively, the crop yield, just a part of the total biomass, can be converted into bio-ethanol (in the case of starch and sugar crops) or biodiesel (in the case of oil crops). In every step of the production chain, residues or rest heat are generated. When only using the crop yield, there is a biomass residue. Biomass residues often remain behind on the field and in this way contribute to soil fertility (Ericson and Nilsson, 2006). When the sugar, starch or oil fraction from the crop yield is subtracted, there will be a crop residue, and, in some cases, also a co-product. Finally, when the sugar, starch or oil is processed further in order to generate bio-ethanol or biodiesel, there will again be some material residue. Often, the residues are used as livestock fodder (Nonhebel, 2004).

The FAO (2006) defines biomass as material of organic origin, in non-fossilized form, such as agricultural crops and forestry products, agricultural and forestry wastes and by-products, manure, microbial biomass, and industrial and household organic waste. Biomass is applied for food or feed (e.g. wheat, maize, sugar), materials (e.g. cotton, wood, paper), or for energy (e.g. maize, sugar, jatropha). At present, biomass is the most important renewable primary energy carrier (Blok, 2006). Biomass is often converted into bio-fuels, renewable secondary energy carriers in solid, liquid or gaseous form. Examples are charcoal, bio-ethanol, biodiesel and biogas (Minnesma and Hisschemöller, 2003; Blok, 2006). Applying biomass in a power plant generates electricity. The various forms of energy derived from biomass are collectively called bio-energy.

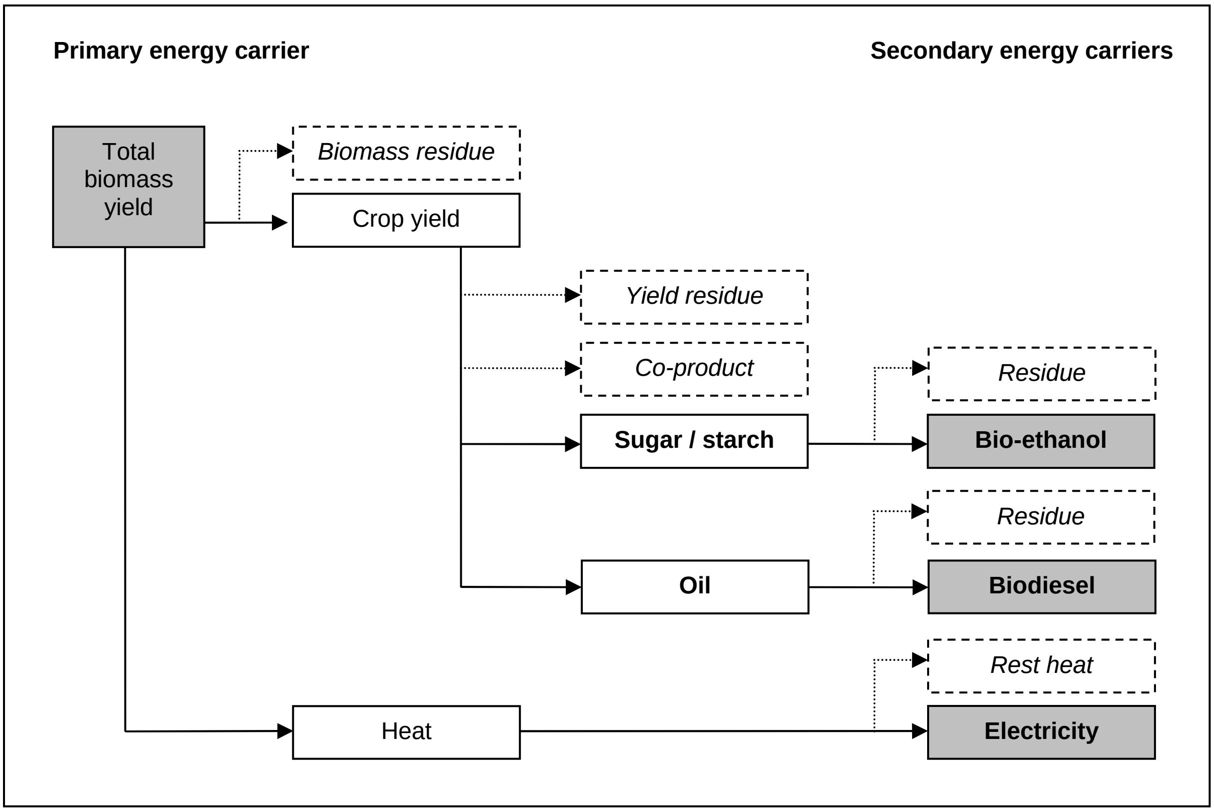

Figure 1.1. From biomass to bio-energy. Total biomass yield can be converted into heat and subsequently into electricity. Alternatively, the crop yield, which is part of the total biomass, can be converted into bio-ethanol (in the case of starch and sugar crops) or biodiesel (in the case of oil crops). In every step in the production chain, residues or rest heat are generated.

2.2 Crops considered in this study

Globally, a limited number of crop types determines total crop production. Theoretically, all crops can be applied for the production of bio-energy. In practice, only some crops dominate the production of bio-energy. These are sugar cane, sugar beet, maize, rapeseed, and soybean (Worldwatch Institute, 2007). Since this study aims to provide a global overview of the water footprints of the main crops that can be used for bio-energy, it included the twelve crops that contribute to 80% of total global crop production. Table 2.1 shows an overview of these twelve crops in order of decreasing annual production. Additionally, the study included jatropha curcas, a tree species that provides oil from the seeds (Banerji et al., 1985).

The composition of biomass determines the availability of energy from a specific biomass type, resulting in differences in combustion energy and options for the production of bio-fuels. This study includes four categories of biomass: starch crops (cereals: barley, maize, rice, rye, sorghum, wheat; and tubers: cassava, potato,), sugar crops (sugar beet, sugar cane), oil crops (rapeseed, soybean), and trees (jatropha). For the assessment of the water footprint of bio-energy, the study follows the method of Hoekstra and Chapagain (2008) to arrive at estimates of the water footprint of crops and the method of Gerbens-Leenes et al. (2008) to translate the water footprint of crops (in m^3/ton) into a water footprint of bio-energy (in m^3/GJ). The latter method is based on the assumption of hypothetical crops, H-crops, with a standardized composition derived from existing crops. Data were obtained from agricultural studies. Appendix 3 shows the twelve H-crops and their main characteristics that formed the basis for the calculations. Based on the sugar or starch content of the H-crop, we calculated the amount of energy that the crop could provide in the form of ethanol. For each oil crop, based on the oil content of the H-crop, we calculated the amount of energy that the crop could provide in the form of biodiesel.

Table 2.1. Overview of the twelve crops that contribute to 80% of total global crop production.

Crop	Average global production 1997-2001 (10^6 ton/yr)
Sugar cane	1258
Maize	603
Wheat	594
Paddy rice	593
Potato	309
Sugar beet	253
Rye	220
Cassava	172
Soybean	160
Barley	140
Sorghum	59
Rapeseed	38
Total	4401
Total global crop production (1997)	5513

Source: FAO (2008).

2.3 Calculation of the water footprint of crops

The water footprint of a product (commodity, good or service) is defined as the volume of freshwater used for the production of that product at the place where it was actually produced (Hoekstra and Chapagain, 2008). In general, the actual water content of products is negligible compared to their water footprint, and water use in the life cycle of the product is dominated by agriculture. The water footprint of a product can be expressed in terms of m^3 per kilogram of product or m^3 per unit of product. In the case of energy, the water footprint can be expressed in terms of m^3 per GJ. Chapagain and Hoekstra (2004) have made an extensive database that includes the water footprint of almost all crops produced worldwide. That study has applied average meteorological data on a national level. The current study did not use the existing database on water footprints of crops but assessed the water footprints of the main crops more specifically per agricultural production location.

Calculations of a water footprint are made by summing daily crop evapotranspiration (mm/day) over the growing period of a crop. This provides information on the crop water requirement. The start of the growing season depends on climatic conditions on the agricultural production location and on individual choices of farmers. For the start of the growing season, the study considered the first option for sowing after the winter period or after a dry season. It assumed that the growing season starts when mean monthly maximum temperatures are above 10°C and when sufficient rain and global radiation is available. Appendix 4 shows the selected start of the growing season per country per crop that formed the input for the calculations of the crop water requirements and the water footprints. For sugar cane and jatropha, perennial crops, the appendix gives no planting data.

The water footprint consists of three components: the green, blue and gray water footprint (Hoekstra and Chapagain, 2008). The green water footprint of a product refers to the rainwater that evaporated during the production process, mainly during crop growth. The blue water footprint refers to surface and groundwater applied for irrigation that evaporated during crop growth. The gray water footprint of a product is the volume of water that becomes polluted during production. It is defined as the amount of water needed to dilute pollutants emitted to the natural water system during the production process to the extent that the quality of the ambient water remains beyond agreed water quality standards. For the main producing countries, this study calculated the crop water requirements for the twelve crops shown in Table 2.1 and for jatropha. It made a distinction between the green and blue water footprint. No assessment was made of the gray water footprint of crops.

For the twelve globally most important crops, the study selected the main producing countries. It derived data from the FAO (2008). For jatropha, it considered production in Brazil, Guatemala, Indonesia and Nicaragua, countries for which data on production were available (Daey Ouwens et al., 2007). Next, it selected the agricultural production location. Information on production locations was derived from the Madison Center for Sustainability and the Global Environment of the University of Wisconsin (2008). Appendix 5 gives an overview of these areas. For these areas, the study selected weather stations providing climatic data that were used as input for the calculations. Data were derived from the database of Müller and Hennings (2000). Appendix 6 gives an overview of the selected weather stations per crop per country.

The calculation of the crop water requirement of a crop (in mm/day) has been done per major production region, using the calculation model CROPWAT 4.3 (FAO, 2007), which is based on the FAO Penman-Monteith method to estimate reference crop evapotranspiration (Allen et al., 1998) and a crop coefficient that corrects for the difference between the actual crop and the reference crop.

The calculation of the green and blue water footprint of a crop (m^3/ton) has been done with the method as developed by Hoekstra and Chapagain (2008). Green water use (m^3/ha) over the length of the growing period is calculated as the sum of the daily volumes of rainwater evapotranspiration. The latter is equal to the crop water requirement except if effective precipitation is less than the crop water requirement. In that case, the rainwater evapotranspiration is equal to effective precipitation. Blue water use (m^3/ha) over the length of the growing period is calculated as the sum of the daily volumes of irrigation-water evapotranspiration. The latter one is equal to the irrigation requirement if this requirement is actually met and otherwise it is equal to the actual effective irrigation. The irrigation requirement is defined as the crop water requirement minus the effective precipitation. In this study, it has been assumed that irrigation requirements are actually met.

The green water footprint of a crop (m^3/ton) is the total green water use over the length of the growing period (m^3/ha) divided by the crop yield (ton/ha). The blue water footprint of a crop (m^3/ton) is the total blue water use over the length of the growing period (m^3/ha) divided by the crop yield (ton/ha).

In general, yields show variation among years. The study therefore calculated average yields over five production years. This was done for the period 1997-2001. Data were derived from the FAO (2008).

2.4 Calculation of the water footprint of heat and electricity from biomass

The energy content of biomass can be expressed in terms of its combustion value. Energy analysis defines the energy content of a substance as the amount of heat that is produced during combustion at 25^o C at 1 bar. It distinguishes between the higher heating value (HHV) and the lower heating value (LHV) (Blok, 2006). For the HHV, energy analysis measures the heat content of water that is the product of the combustion process in the liquid form; in the case of LHV it measures the heat content in the gaseous form.

For the calculation of the water footprint of heat from biomass, the study has followed the method as described by Gerbens-Leenes et al. (2008). In this method, the energy yield of a crop (GJ/ton) is calculated by combining data on the heat of combustion of plant components (as shown in Table 2.2) with information on the composition, harvest index and dry mass fraction of a crop (as shown in Appendix 3):

$$E_{heat}(c) = HI(c) \times DMF_y(c) \times \sum_{i=1}^{5}\left(f_{y,i} \times HHV_i\right) + \left(1 - HI(c)\right) \times DMF_r(c) \times \sum_{i=1}^{5}\left(f_{r,i} \times HHV_i\right)$$

$E_{heat}(c)$ is the energy yield of crop c in the form of heat (GJ/ton), $HI(c)$ is the harvest index of crop c (gram/gram), $DMF_y(c)$ is the dry mass fraction of the crop yield (gram/gram), $DMF_r(c)$ is the dry mass fraction in the rest fraction (i.e. in the residue biomass), $f_{y,i}$ is the fraction of component i in the dry mass of the crop yield (gram/gram), $f_{r,i}$ is the fraction of component i in the dry mass of the rest fraction (gram/gram) and HHV_i is the higher heating value of component i (kJ/gram).

Table 2.2. Higher heating value (HHV) for six major groups of plant components.

Plant component	HHV (kJ/gram)
Carbohydrates	17.3
Proteins	22.7
Fats	37.7
Lignins	29.9
Organic acids	13.9
Minerals (K,Ca,P,S)	0.0

Source: Penning de Vries (1989)

The generation of electricity from biomass is generally done by heating water to superheated steam with temperatures higher than the evaporation temperature of water. There is a limit on the maximum amount of efficiency any possible engine can obtain. This limit depends on the difference between the hot and cold temperature reservoirs. According to Carnot's theorem no engine operating between two heat reservoirs can be more efficient than a Carnot engine operating between the same reservoirs (Carnot, 1824). The theorem formed the basis for the formulation of the second law of thermodynamics. When transforming thermal energy into mechanical energy, the thermal efficiency of a heat engine is the percentage of energy transformed into work. This means that, theoretically, there is a maximum to the amount of electricity that can be generated in a power plant. This theoretical maximum efficiency η_{max} is based on the Carnot's rule (Carnot, 1824). The value of η_{max} of any heat engine depends only on the temperatures it operates between:

$$\eta_{\max} = 1 - \frac{T_c}{T_h}$$

where T_c is the temperature of the cold source and T_h the temperature of the hot source (in ^{o}K). The equation shows that the efficiency of electricity generation increases with increasing temperature of the hot source. With temperatures of about 873 ^{O}K, a steam cycle plant could reach a theoretic maximum efficiency of 66%. Typical efficiencies for steam-cycle plants are lower, about 40%, of combined-cycle power plants with temperatures of 673 ^{O}K 50-55%. A steam-cycle plant can be fuelled with any type of fuel, while the combined-cycle plants can use only clean fuels such as natural gas (Blok, 2006). A new technology is gasification of biomass for electricity production. This technology is termed 'Biomass fired Integrated Gasifier Combined Cycle (BIG/CC). It can be applied for biomass with a moisture content below 70% and an ash content below 10-20% (DM) (Faay, 1997). Temperatures are lower however, 720 ^{o}K, reaching an efficiency of 59% (Blok, 2006).

For the generation of electricity from biomass, industry can apply the heat that comes available from the combustion of total biomass. The energy in the form of electricity from crop *c* (GJ/ton) depends on the efficiency with which energy in the form of biomass-heat can be transformed into electricity:

$$E_{electr}(c) = \eta \times E_{heat}(c)$$

For the value of the efficiency η the study applied the theoretically maximum efficiency of 59% based on the Carnot rule and a temperature of 720 ^{o}K.

The water footprint of heat from a crop *c* (m^3/GJ) is calculated by dividing the water footprint of the crop (m^3/ton) by the heat content of the crop (GJ/ton). The water footprint of biomass electricity from a crop *c* (m^3/GJ) is calculated by dividing the water footprint of the crop (m^3/ton) by the electricity output per crop unit (GJ/ton):

$$WF_{heat}(c) = \frac{WF(c)}{E_{heat}(c)}\ ; \qquad WF_{electr}(c) = \frac{WF(c)}{E_{electr}(c)}$$

2.5 Calculation of the water footprint of first-generation bio-fuels

At present, bio-ethanol is produced from sugars from sugar cane or sugar beet, or from starch hydrolysed into sugars derived from crops such as maize, wheat or cassava (Worldwatch Institute, 2007). Under anaerobic conditions, the sugar in plants naturally ferments into acids and alcohols (mainly ethanol). For thousands of years, people have applied yeasts to fasten fermentation. The main metabolic pathway involved in the ethanol fermentation is glycolysis through which one molecule of glucose is metabolized and two molecules of pyruvate are produced (Verkerk et al., 1989; Bai et al., 2008). Under anaerobic conditions, the pyruvate is further reduced to ethanol with the release of CO_2. The overall reaction is $C_6H_{12}O_6 \rightarrow 2\ C_2H_5OH + 2CO_2$. Theoretically, the maximum yield of ethanol is 511 grams of ethanol and 489 grams of carbon dioxide per kg of glucose metabolized (or 530 grams of ethanol per kg of starch). Often, various by-products are also produced during fermentation, for example, glycerol (Bai et al., 2008). During ethanol fermentation, yeast cells suffer from stresses such as ethanol accumulation inhibiting yeast cell growth and ethanol production. The final ethanol concentration is about 10-12% (Catsberg and Kempen-van Dommelen, 1997; Bai et al, 2008). The ethanol fermentation industry, therefore, applies a tanks-in-series system to alleviate product inhibition. Today, the ethanol fermentation industry can reach a yield of 90-93% of the theoretical value of glucose to ethanol (Bai et al., 2008).

Oilseed crops, such as rapeseed, soybean, and jatropha, are used to produce straight vegetable oil or biodiesel. Straight vegetable oil is oil extracted from an oilseed crop and directly applied for energy purposes (Worldwatch Institute, 2007). An example is olive oil applied for lightning. The use of oil lamps extends from prehistory to the present day. Olive oil lamps continued in wide use in countries around the Mediterranean Sea well into the 19th century. Due to its chemical properties, such as for example the high viscosity at low temperatures, it is often difficult to use straight vegetable oil as a bio-fuel for transport in diesel engines (Worldwatch Institute, 2007). In countries with warm climates, the relatively high temperatures prevent the oil from thickening and the straight vegetable oil is a viable fuel. In countries with temperate climates, the oil cannot be applied for transport and needs additional treatment to manufacture a biodiesel less sensitive to lower temperatures. Biodiesel is manufactured in a chemical reaction termed transesterification in which the oil reacts with an alcohol resulting in an alkyl ester of the fatty acid with glycerine molecules as the primary co-product. Methanol has been the most commonly used alcohol for the manufacture. In Europe, rapeseed oil is the dominant feedstock for biodiesel, with some sunflower oil also used. In the US, the main feedstock is soybean oil, in tropical and subtropical countries palm oil, coconut oil and jatropha oil are used (Worldwatch Institute, 2007).

When calculating the use of natural resources, the whole life cycle of a product should be taken into account. The use of water, however, is dominated by the first link of the production chain, agriculture. Ethanol production, for example, requires about 21 litres of water per litre of ethanol. Moreover, this water is often reused (Institute for Agriculture and Trade Policy, 2007). This study therefore only took water requirements in agriculture into account and neglected water use in the industrial links of the production chain.

The ethanol-energy yield of a crop (in GJ/ton) has been calculated in this study as follows:

$$E_{ethanol}(c) = DMF_y(c) \times f_{carbohydr}(c) \times f_{ethanol} \times HHV_{ethanol}$$

where $DMF_y(c)$ is the dry mass fraction in the crop yield (gram/gram), $f_{carbohydr}(c)$ the fraction of carbohydrates in the dry mass of the crop yield (gram/gram), $f_{ethanol}$ the amount of ethanol obtained per unit of carbohydrate (gram/gram) and $HHV_{ethanol}$ the higher heating value of ethanol (kJ/gram). For the amount of ethanol per unit of sugar, we assumed the theoretical maximum value of 0.51 gram/gram, for starch, 0.53 gram/gram (Rosillo-Calle et al., 2007).

The biodiesel-energy yield of a crop (in GJ/ton) has been calculated as follows:

$$E_{diesel}(c) = DMF_y(c) \times f_{fat}(c) \times f_{diesel} \times HHV_{diesel}$$

where $DMF_y(c)$ is the dry mass fraction in the crop yield (gram/gram), $f_{fat}(c)$ the fraction of fats in the dry mass of the crop yield (gram/gram), f_{diesel} the amount of biodiesel obtained per unit of fat (gram/gram) and HHV_{diesel} the higher heating value of biodiesel (kJ/gram). For the fraction biodiesel per fat weight we assumed the value 1.

The higher heating values of ethanol and biodiesel are given in Table 2.3. The fractions of carbohydrates and fats in the dry mass of crop yields is given in Appendix 3.

Table 2.3. Higher heating values (HHV) of ethanol and biodiesel.

	HHV (kJ/gram)
Biodiesel	37.7
Ethanol	29.7

Source: Penning de Vries (1989); Verkerk et al. (1986).

The water footprint of ethanol-energy from a crop *c* (m^3/GJ) is calculated by dividing the water footprint of the crop (m^3/ton) by the ethanol-energy yield of the crop (GJ/ton). The water footprint of biodiesel-energy from a crop *c* (m^3/GJ) is calculated in a similar way:

$$WF_{ethanol}(c) = \frac{WF(c)}{E_{ethanol}(c)}; \qquad WF_{diesel}(c) = \frac{WF(c)}{E_{diesel}(c)}$$

For the calculation of the water footprint of first-generation bio-fuels, this study fully allocated the water footprint of the crop to the bio-fuels derived, assuming that the value of the residues of production is much lower than the value of the bio-fuel.

2.6 Calculation of the water footprint of next-generation bio-fuels

First-generation bio-fuels concern the presently available bio-fuels produced using conventional technology, i.e. fermentation of carbohydrates into ethanol, and extracting and processing oil from oil crops. The next-generation bio-fuels concern the future available bio-fuels produced using new technology under development that aims to also convert residues and wastes from crops into liquid bio-fuels, e.g. ethanol (Worldwatch Institute, 2007). In this way, the production of bio-fuel per unit of crop can increase substantially.

Biomass not only contains starch, sugar and oil that can be processed into bio-fuels; it also contains large amounts of cellulosic biomass. So far, the cellulosic fraction could be used for energy by burning it to provide heat and produce electricity. It is expected that, in the near future, these cellulosic fractions will form an attractive source for the production of liquid, next generation bio-fuels.

For next-generation bio-fuels, industry can apply total biomass, including wastes. It is not yet clear what efficiency will be achieved in converting total biomass into bio-fuel. It is safe to assume, however, that the water footprint of next-generation bio-fuels will never be lower than the water footprint of the crop (m^3/ton) divided by the energy content of the crop (GJ/ton), where the latter is expressed in terms of its higher heating value (HHV).

3. Results

3.1 Crop production, crop water requirements and irrigation requirements

Appendix 7 shows the main crops in order of declining global production and the contribution to global production per crop per country. In this way, the study covers about 80% of global crop production. Some countries have a large contribution to global production. For example, Brazil produces 27% of the globally available sugar cane; the United States almost half of the global soybean production, 40% of the maize, and one quarter of the sorghum; China 18% of all wheat, one third of the paddy rice, one fifth of the potatoes, and 27% of the rapeseed. Half of the global production of rye takes place in Russia and Germany, while Nigeria shows the largest contribution to the production of cassava. For other crops, such as sugar beet and barley, production is distributed more evenly.

Appendix 8 shows the crop water and irrigation requirements for the main crops over the growth period per country. The appendix shows that on almost every crop location, irrigation is required. Exceptions are sugar beet grown in Japan; maize from South Africa; wheat from Australia; cassava from Nigeria, Angola, Benin, Guinea, the Philippines, Viet Nam and India; potato from Bangladesh, Peru and Japan; sorghum from Nigeria, Ethiopia, Chad and Venezuela; and rapeseed from Bangladesh. In some countries, crop water requirements are completely or almost completely covered with irrigation water. These crops and countries are: sugar cane from Argentina (96%) and Egypt (92%); wheat from Argentina (100%), Kazakhstan (98%) and Uzbekistan (98%); potato and barley from Kazakhstan (100%); sorghum from Yemen (100%); and soybean from Brazil (95%). For the other crops and production locations, irrigation requirements find themselves in between the two extremes.

3.2 The water footprint of biomass

Appendix 9 shows the water footprints for the main crops. It shows the total water footprint per crop per country, as well as the blue and green water footprint. The water footprints show large variation for the same crop type, dependant on agricultural production system applied and climate conditions. Table 3.1 gives an overview of the extreme values of total water footprints and blue water footprints per crop. Most total water footprints show variation of a factor of four to fifteen, with two exceptions. These are the values for wheat and sorghum that show a difference of a factor of twenty and forty seven respectively. Kazakhstan is three times the country with the largest total and blue water footprint for a crop (barley, potato and wheat).

Table 3.1. Overview of the extreme values of total water footprints and blue water footprints per crop (m^3/ton)

Crop	Country	Extreme values total water footprint m^3/ton		Extreme values blue water footprint m^3/ton
Barley	Ireland	448	India	147
	Kazakhstan	6540	Kazakhstan	6510
Cassava	India	191	India/Vietnam	0
	Cote d'Ivoire	1437	Cote d'Ivoire	1437
Jatropha	Brazil	3222	Brazil	1170
	India	21729	India	14344
Maize	Spain	407	South Africa	0
	Nigeria	3783	Nigeria	2267
Rapeseed	Germany	1482	Bangladesh	0
	India	9900	Pakistan	4130
Paddy rice	Egypt	634	Bangladesh	19
	Nigeria	6471	Nigeria	4629
Potato	Spain	85	Japan	0
	Kazakhstan	922	Kazakhstan	922
Rye	Sweden	637	Austria	245
	Russia	2620	Russia	1220
Sorghum	Egypt	525	Venezuela/Chad	0
	Niger	24700	Sudan	14117
Soybean	Italy	1442	Paraguay	546
	India	7540	Indonesia	2583
Sugar beet	Morocco	56	Japan	0
	Russia	455	Russia	376
Sugar cane	Peru	108	Peru	8
	Cuba	524	Pakistan	217
Wheat	Denmark	513	Australia	0
	Kazakhstan	10178	Kazakhstan	9989

3.3 The water footprint of heat and electricity from biomass

Appendix 10 shows the water footprint of heat that derives from the combustion of biomass (m^3 per GJ heat). The water footprint of electricity derived from biomass (m^3 per GJ electricity) is shown in Appendix 11. The data differ per crop and per country. Both appendices show the distinction into a blue and a green water footprint. Table 3.2 shows the total weighted global average water footprint for thirteen crops providing electricity. It is assumed that not only crop yields, but total biomass yields are applied for the generation.

Table 3.2. Total weighted global average water footprint for thirteen crops providing electricity (m^3/GJ). It is assumed that not only crop yields, but total biomass yields are applied for the generation of the electricity

Crop	Total water footprint	Blue water footprint	Green water footprint
	m^3 per GJ electricity		
Sugar beet	46	27	19
Maize	50	20	30
Sugar cane	50	27	23
Barley	70	39	31
Rye	77	36	42
Paddy rice	85	31	54
Wheat	93	54	39
Potato	105	47	58
Cassava	148	21	127
Soybean	173	95	78
Sorghum	180	78	102
Rapeseed	383	229	154
Jatropha[a]	396	231	165

[a] average numbers for five countries (India, Indonesia, Nicaragua, Brazil and Guatemala)

3.4 The water footprint of first-generation bio-fuels

3.4.1 Bio-fuel energy production per crop unit

Table 3.3 shows the energy provided by ethanol (HHV ethanol in MJ/kg fresh weight of the crop) from the two sugar and eight starch providing crops that were included in this study. The table shows that there are three categories of crops: the sugar providing crops and one starch providing crop showing relatively low values for energy provided by ethanol (sugar beet, sugar cane and potato), the category of starch providing crops with relatively large values for energy provided by ethanol (sorghum, maize, wheat, barley, paddy rice and rye) and one category in between (cassava). These differences are caused by differences in the water contents of the crops, where a large water content relates to relatively low energy values provided by ethanol. Table 3.3 also shows the energy provided by oil from the three oil providing crops included in this study. The HHV of oil from soybean is smallest, about half the value of rapeseed or jatropha.

Table 3.3. Energy provided by ethanol from the two sugar and ten starch providing crops that were included in this study, as well as the energy provided by oil from the three oil providing crops.

Crop	MJ of bio-fuel per kg fresh weight crop
Ethanol from sugar	
Sugar cane	2.3
Sugar beet	2.6
Ethanol from starch	
Potato	3.1
Cassava	5.2
Sorghum	10.0
Maize	10.0
Wheat	10.2
Barley	10.2
Paddy rice	10.5
Rye	10.5
Biodiesel from oil	
Soybean	6.4
Rapeseed	11.7
Jatropha	12.8

3.4.2 The water footprint of bio-ethanol

Appendix 12 shows the water footprint of ethanol for two sugar and eight starch crops for the main producing countries. The appendix shows the total, as well as the blue and green water footprint (m^3 per GJ ethanol) in order of increasing values. Figure 3.1 shows the lowest value, the highest value and the weighted average global value of the water footprint for energy for ten crops providing ethanol. The figure shows the enormous variation in the total water footprint among crops. Especially sorghum shows a large variation, which is mainly caused by the unfavourable conditions in Niger and high production efficiency in Egypt.

Figure 3.2 shows the weighted global average water footprint for the ten crops providing ethanol. It shows that differences among crops are large. At present, sugar beet is the most favourable crop, sorghum the most unfavourable with a difference of a factor of seven. When data for the two main ethanol producing countries, Brazil and the United States are compared, Appendix 12 shows that in Brazil ethanol from sugar cane is more favourable in terms of water than maize (99 versus 140 m^3/GJ ethanol), while in the United States, maize is more attractive from a water point of view than sugarcane (78 versus 104 m^3/GJ ethanol). Figure 3.2 shows the distinction between green and blue water. As a global average, the blue water footprint of cassava is smallest. Other favourable crops are sugar beet, potato, maize and sugar cane. In terms of blue water, sorghum is unfavourable.

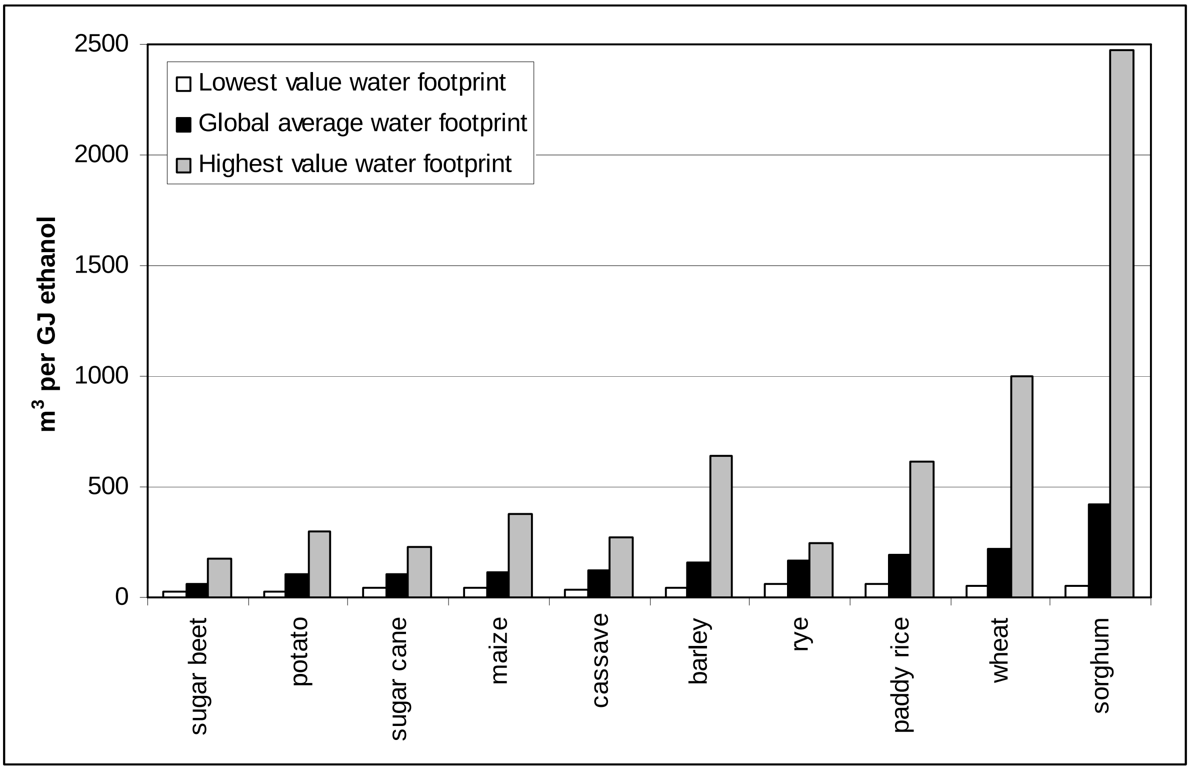

Figure 3.1. Lowest value, highest value and weighted average global value of the water footprint for energy for ten crops providing ethanol.

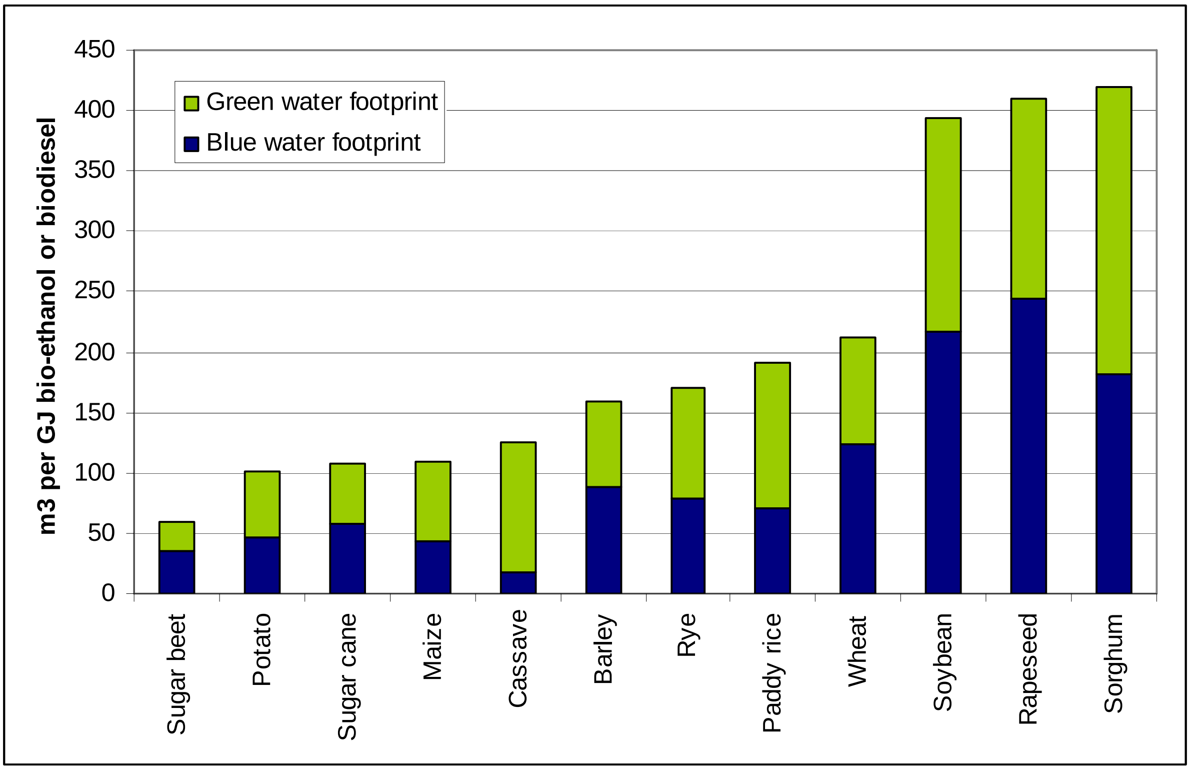

Figure 3.2. The weighted global average water footprint for ten crops providing ethanol and for two crops providing oil for biodiesel.

Table 3.4. Total weighted global average water footprint for ten crops providing ethanol and three crops providing biodiesel (m^3/GJ), as well as the blue and green water footprint. The table also shows the amount of water needed for a specific crop to produce one litre of ethanol or one litre of biodiesel (l/l)

Crop	Total water footprint (m^3/GJ)	Blue water footprint (m^3/GJ)	Green water footprint (m^3/GJ)	Total water (litre/litre)	Blue water (litre/litre)	Green water (litre/litre)
Ethanol	m^3 per GJ ethanol			litres water per litre ethanol		
Sugar beet	59	35	24	1388	822	566
Potato	103	46	56	2399	1078	1321
Sugar cane	108	58	49	2516	1364	1152
Maize	110	43	67	2570	1013	1557
Cassava	125	18	107	2926	420	2506
Barley	159	89	70	3727	2083	1644
Rye	171	79	92	3990	1846	2143
Paddy rice	191	70	121	4476	1641	2835
Wheat	211	123	89	4946	2873	2073
Sorghum	419	182	238	9812	4254	5558
Biodiesel	m^3 per GJ biodiesel			litres water per litre biodiesel		
Soybean	394	217	177	13676	7521	6155
Rapeseed	409	245	165	14201	8487	5714
Jatropha[a]	574	335	239	19924	11636	8288

[a] average numbers for five countries (India, Indonesia, Nicaragua, Brazil and Guatemala)

Table 3.4 shows the total weighted global average water footprint for the ten crops providing ethanol, as well as the blue and green water footprint. The table also shows the amount of water needed for a specific crop to produce one litre of ethanol. On average, it takes 1400 litres of water to produce one litre of ethanol from sugar beet, 2400 litres for one litre of ethanol from potato, 2500 litres from sugar cane and 2600 litres from maize. Sorghum is the most inefficient crop, 9800 litres for one litre ethanol. Irrigation is smallest for cassava, 400 litres of blue water for one litre of ethanol, followed by 800 litres for sugar beet and 1000 litres for maize. Sorghum is the crop showing the largest blue water footprint, 4250 litres per litre ethanol.

As one can see from a comparison of Tables 3.2 and 3.4, sugar beet is the most efficient crop in terms of ethanol and electricity. The other crops show a different order for the efficiency in which electricity and ethanol are produced. In general, however, the production of ethanol of only part of the crop is less water efficient than the production of electricity from total biomass.

3.4.3 The water footprint of biodiesel

Appendix 13 shows the water footprint of biodiesel derived from soybean, rapeseed and jatropha for the main producing countries. The appendix shows the total water footprint, and the blue and green water footprint (m^3 per GJ biodiesel) in order of increasing total water contents. For rapeseed, western Europe shows the smallest water footprints, Asia the largest. Especially in India, rapeseed has a large blue water footprint. For soybean, Italy, Paraguay and Argentina have the smallest water footprints, India the largest. Biodiesel from jatropha is produced in the most water efficient way in Brazil, and the most water inefficient in India. Table 3.4 shows the total weighted global average water footprint for biodiesel (soybean and rapeseed) and the average water footprint for jatropha, as well as the blue and green water footprint. The table also shows the amount of water needed to produce one litre of biodiesel. On average, it takes 14,000 litres of water to produce one litre of biodiesel from soybean or rapeseed, and 20,000 litres for one litre of biodiesel from jatropha.

3.5 The water footprint of next-generation bio-fuels

For next-generation bio-fuels, the total biomass of a crop can be applied. When the efficiency of the production of next-generation bio-fuels lies in the same order of magnitude as the production of electricity from biomass, which upper limit is about 59%, the results shown in Appendix 11 and Table 3.2 form a lower limit for the water footprint of these next-generation bio-fuels.

4. Discussion

This study builds on two earlier studies: the water footprints of nations (Chapagain and Hoekstra, 2004; Hoekstra and Chapagain, 2007, 2008) and the water footprint of bio-energy and other primary energy carriers (Gerbens-Leenes et al., 2008). For the crops that can contribute to bio-energy, it refines the study of Chapagain and Hoekstra (2004). This is done by taking the actual production locations into account for the calculation of the crop water requirements and by using better estimates for the start of the growing season, that depends on favourable weather conditions at the specific location. Sometimes, this results in large differences. For example, this study finds results for crop water requirements for sugar beet grown in Russia of 800 mm over the growing period of the crop, where the earlier study has calculated 350 mm. Other times results are similar. Both studies find a crop water requirement of 500 mm for sugar beet grown in France. The differences indicate that the methodology applied is sensitive to input of climatic data and assumptions concerning the start of the growing season. An additional refinement is that the study differentiates between blue and green water and in this way provides a more detailed insight into the water footprints of crops in a specific country. Similar to the study of Chapagain and Hoekstra (2004), the calculations in the study are based on crop water requirements. When actual water availability is lower and water stress occurs leading to a decrease of yield levels, the study overestimates the crop water requirements.

Gerbens-Leenes et al. (2008) have assessed the water footprint of primary energy carriers from biomass in terms of the water volume needed to provide a unit of energy (in m^3/GJ). That study considered the energy content in the form of heat from the total biomass. Energy, however, is often not demanded in the form of heat but in the form of electricity or fuel. In society, energy is used for space heating, industrial production and transportation. In industrialized countries, each of these functions accounts for about 30% of demand (Blok, 2006). For space heating, energy can be applied in the form of heat. Theoretically, all potentially available energy of biomass can be applied. Industrial production and transportation require energy in the form of power. Although according to the first law of thermodynamics, the law of conservation of energy, no energy can be created nor destroyed, the conversion of energy into other forms, the secondary energy carriers, can cause substantial losses. This study extends the research from biomass-heat to bio-electricity and bio-fuels. It takes into account that at present the theoretically maximum available energy from biomass is partly lost when conversions take place. The values for the water footprints of bio-electricity and bio-fuels are therefore larger than the water footprint of biomass heat.

The study took the main crops into account that contribute to 80% of the total arable production. Theoretically, all these crops can be applied for energy, including crops like rice and rye that are mainly applied for food. For the use of natural resources for a specific crop, it does not matter whether the crop is applied for energy or for food. By including all main crops, the study provides a detailed overview of the water consequences of the production of biomass for energy. It shows that some food crops, including rice, are more water efficient in producing a unit of ethanol, biodiesel or electricity than some typical energy crops, such as rapeseed or jatropha. The ethical discussion whether food crops can be used for energy should be extended to the discussion whether we should apply our natural resource base for food or for energy.

In assessing the water footprint of heat, electricity and fuels from biomass, we looked at the water footprint of the *gross* energy output from crops. We did not study the energy inputs in the production chain, like the energy requirements in the agricultural system (e.g. energy use for the production of fertilizers and pesticides) or the energy use during the industrial production of the bio-fuel. For high-input agricultural systems, the energy input is substantial (Pimentel and Patzek, 2005) so that net energy yields are smaller than calculated in this report. This means that this report underestimates the water footprint of bio-energy from agricultural systems with relatively large energy inputs.

The results presented in this study are based on rough estimates of freshwater requirements in crop production and on theoretically maximum conversion efficiencies for the secondary energy carriers. For the assessment of the water footprint of bio-energy, the study integrated data from several sources, each of which adds a degree of uncertainty. For example, the calculations using the model CROPWAT required input of meteorological data that are averages over several years rather than data for a specific year. The data presented do thus not reflect annual variations. The factors mentioned above imply that results presented here are indicative. However, the differences in water footprints are so large that the conclusions can be supported. In this way, the study provides new insights into the relationship between the energy and the water system.

5. Conclusions

This study provides a detailed overview of crop water requirements and water footprints of the main arable crops for the main producing countries that contribute to 80% of the total global arable production. These crops are barley, cassava, maize, potato, rapeseed, rice, rye, sorghum, soybean, sugar beet, sugar cane and wheat. For these crops, the study refines the research of Chapagain and Hoekstra (2004) by making more detailed assessments based on crop locations and related weather conditions within countries and by distinguishing between green and blue water. The study also includes jatropha, an energy crop that cannot be used as food. Although only some crops are presently used for bio-energy, mainly sugar cane, sugar beet, maize, wheat, cassava, rapeseed, soybean and jatropha, theoretically all crops can be a source of bio-energy. To provide detailed information on the water footprint of energy, the study includes all crops that could be a source of energy, also the crops that are presently not used for energy purposes, e.g. paddy rice.

Results show that there are large differences in crop water requirements among countries that are caused by differences in climate. The crop water requirement of sugar beet grown in Iran, for example, is twice the weighted global average value. Climatic factors in combination with agricultural practice determine differences among water footprints. When yield levels are relatively low, water footprints are high and the other way around. For example, in Kazakhstan, yields of barley, potato and wheat are relatively low. In combination with unfavourable climatic factors, this results in high values for the water footprints. Conditions in Denmark are favourable, resulting in relatively low crop water requirements for wheat.

Large differences are found among the water footprints. In general, it is more efficient to use the total biomass, including stems and leaves, and generate electricity than producing a bio-fuel. For the crops included in the study, the weighted average water footprint is up to a factor two smaller for electricity than for ethanol or biodiesel. The difference is caused by the fraction of the crop that can be applied. For electricity, the total biomass can be used; for ethanol or biodiesel only the starch or oil fraction of the yield. In general, when considering bio-fuels for transportation, the water footprint of ethanol is smaller than the water footprint of biodiesel. For the generation of electricity, sugar beet, maize and sugar cane with water footprints of about 50 m^3/GJ are the most favourable crops, followed by barley, rye and rice with water footprints of about 70-80 m^3/GJ. Rapeseed and jatropha, typical energy crops, showing water footprints of about 400 m^3/GJ are the most unfavourable crops. For the production of ethanol, two crops grown in a temperate climate, sugar beet and potato, with water footprints of 60 and 100 m^3/GJ respectively, are the most favourable crops, followed by a crop typical for a warm climate, sugar cane also showing a water footprint of about 110 m^3/GJ. Values for maize and cassava show the same order of magnitude. With a water footprint of 400 m^3/GJ, sorghum is by far the most unfavourable crop. For the production of biodiesel, soybean and rapeseed, crops that are also grown for food, show the most favourable water footprint of 400 m^3/GJ; jatropha has the most unfavourable water footprint of about 600 m^3/GJ.

The scientific and the international political community promote a shift towards CO_2-neutral energy carriers, such as biomass, to avoid emissions of greenhouse gasses. This study has shown that the production of biomass goes along with large water requirements. Already there are reasons for profound concern in several regions and countries with limited water resources if food and fibre needs of future generations can be met. If a shift towards a larger contribution of bio-energy to total energy supply takes place, results of this study can be used to select the crops and countries that (under current production circumstances) produce bio-energy in the most water efficient way.

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Appendix 1. List of symbols

Symbol	Unit	Explanation
DMF	gram/gram	dry mass fraction
E_{diesel}	GJ/ton	diesel-energy yield of a crop
E_{electr}	GJ/ton	energy yield of a crop in the form electricity
$E_{ethanol}$	GJ/ton	ethanol-energy yield of a crop
E_{heat}	GJ/ton	energy yield of a crop in the form of heat
f_i	gram/gram	fraction of component *i* in the dry mass of the crop yield
HHV	kJ/gram	higher heating value
HI	gram/gram	harvest index
LHV	kJ/gram	lower heating value
WF	m^3/ton	water footprint of a crop
$WF_{biodiesel}$	m^3/GJ	water footprint of energy in the form of biodiesel
WF_{electr}	m^3/GJ	water footprint of energy in the form of bio-electricity
$WF_{ethanol}$	m^3/GJ	water footprint of energy in the form of bio-ethanol
WF_{heat}	m^3/GJ	water footprint of energy in the form of bio-heat
η	-	efficiency in electricity production from heat
η_{max}	-	theoretical maximum efficiency in electricity production from heat

Appendix 2. Glossary

Biodiesel – Secondary energy carrier manufactured in a chemical reaction termed transesterification in which the oil reacts with an alcohol resulting in an alkyl ester of the fatty acid.

Bio-energy – Energy derived from biomass.

Bio-fuel – Renewable secondary energy carrier derived from biomass in solid, liquid or gaseous form. Examples are charcoal, ethanol, biodiesel and biogas.

Biomass – Material in non-fossilized form. Examples are agricultural crops, forestry products, agricultural and forestry wastes and by-products, manure, microbial biomass, and industrial and household organic waste.

Blue water footprint – Volume of surface and groundwater evaporated as a result of the production of a product or service. For example, for crop production, the blue water footprint is defined as the sum of the evaporation of irrigation water from the field and the evaporation of water from irrigation canals and artificial storage reservoirs. It is the amount of water withdrawn from ground- or surface water that does not return to the system from which it came.

Crop yield – Weight of harvested crop per unit of harvested area.

Ethanol – Alcohol (C_2H_5OH) that can be produced from sugar or starch under anaerobic conditions by fermentation.

Energy carrier – Substance that is predominantly used as a source of energy.

Evapotranspiration – Evaporation from the soil and soil surface where crops are grown, including the transpiration of water that actually passes crops.

First-generation bio-fuels – Presently available bio-fuels produced using conventional technology, i.e. fermentation of carbohydrates into ethanol, and extracting and processing oil from oil crops.

Fossil energy – Non-renewable energy derived from plant material stored in the earth's crust for millions of years, such as oil, natural gas and coal. The use of fossil energy causes emissions of carbondioxide that contributes to global warming.

Green water footprint – Volume of rainwater that evaporated during the production process. This is mainly relevant for agricultural products (e.g. crops or trees) where it refers to the total rainwater evapotranspiration (from fields and plants).

Harvest index – Ratio of crop yield to total biomass yield.

Next-generation bio-fuels – Future available bio-fuels produced using new technology under development that aims to convert residues and wastes from crops into liquid secondary energy carriers, e.g. ethanol.

Primary energy carrier – Energy carrier directly derived from a natural source without any conversion process.

Renewable energy – Energy deriving from renewable sources. Examples are bio-energy, wind energy and solar energy.

Secondary energy carrier – Energy carrier that does not directly derive from a natural source, but is the product of a conversion process.

Straight vegetable oil – Oil extracted from an oilseed crop and directly applied for energy purposes.

Water footprint – an indicator of water use that looks at both direct and indirect water use. Water use is measured in terms of water volumes consumed (evaporated) and/or polluted. A water footprint can be calculated for any well-defined group of consumers (e.g. an individual or family or the inhabitants of a village, city, province, state or nation) or producers (e.g. a public organization, private enterprise or whole economic sector). The water footprint is a geographically and temporally explicit indicator, not only showing volumes of water consumption and pollution, but also the locations and timing.

Water footprint of a product – The water footprint of a product (good or service) is the total volume of fresh water used to produce the product, summed over the various steps of the production chain. The water footprint of a product refers not only to the total volume of water used; it also refers to where and when the water is used.

Appendix 3. Main characteristics for twelve crops.

	cassava	barley	maize	paddy rice	potato	Rapeseed	rye	sorghum	soybean	sugar cane	sugar beet	wheat
Harvest Index	0.70[a]	0.42[a]	0.45[a]	0.42	0.70[a]	0.32[a]	0.42	0.42	0.40[a]	0.60[a]	0.66[a]	0.42[a]
Economic yield	tuber[b]	ear + grain[b]	whole tops[b]	inflor + grain	tuber [b]	inflor + seed[d]	ear + grain[b]	ear + grain[b]	beans[a]	whole tops[a]	beet[a]	ear + grain[b]
Dry mass[b]	0.38	0.85	0.85	0.85	0.25	0.74	0.85	0.85	0.92	0.27	0.21	0.85
Composition dry mass (g /100 g)[c]												
Carbohydrates	87	76	75	76	78	7	76	76	29	57	82	76
Proteins	3	12	8	8	9	22	12	12	37	7	5	12
Fats	1	2	4	2	0	42	2	2	18	2	0	2
Lignin	3	6	11	12	3	2	6	6	6	22	5	6
Organic acids	3	2	1	1	5	1	2	2	5	6	4	2
Minerals (K,Ca,P,S)	3	2	1	1	5	26	2	2	5	6	4	2
Rest fraction	leaves	shells	stems	stems	leaves	leaves	stems	stems	leaves	stems	leaves	stems
Dry mass[b]	0.38	0.85	0.85	0.85	0.13	0.13	0.85	0.85	0.15	0.27	0.21	0.85
Composition dry mass (g /100 g)[c]												
Carbohydrates	52	62	62	62	52	52	62	62	52	62	52	62
Proteins	25	10	10	10	25	25	10	10	25	10	25	10
Fats	5	2	2	2	5	5	2	2	5	2	5	2
Lignin	5	20	20	20	5	5	20	20	5	20	5	20
Organic acids	5	2	2	2	5	5	2	2	5	2	5	2
Minerals (K,Ca,P,S)	8	4	4	4	8	8	4	4	8	4	8	4

Data on composition, harvest index and dry mass are averages of existing crops. Data were derived from agricultural studies.

a. Source: Goudriaan et al., 2001
b. Source: Penning de Vries et al., 1989
c. Source: Habekotté, 1997
d. Source: Akthar, 2004
e. Assumption
f. Source: Nonhebel, 2002

Appendix 4. Average annual crop yield and start of the growing season per country per crop

	Average annual crop yield (tons/ha 1997-2001)[a]	Start of the growing season [b]
Sugar beet		
France	71.1	1-Apr
United States	49.1	1-Apr
Germany	55.5	1-Apr
Turkey	40.9	1-Jan
Ukraine	17.3	1-Apr
China	26.4	30-Apr
Italy	48.1	1-Mar
Poland	36.9	1-Apr
Russian federation	18.2	15-Apr
United Kingdom	53.3	1-Apr
Netherlands	57.0	1-Apr
Belgium-Luxemburg	39.1	1-Apr
Iran	27.0	1-Mar
Japan	55.5	1-Feb
Austria	62.8	1-Apr
Belarus	26.9	1-Apr
Chile	63.3	1-Oct
Czech republic	43.9	15-Apr
Denmark	54.0	15-Apr
Egypt	46.6	1-Nov
Greece	58.9	1-Feb
Hungary	40.5	1-Apr
Ireland	46.2	1-Apr
Moldova	18.9	1-Apr
Morocco	51.8	1-Nov
Romania	20.2	1-Apr
Serbia	34.8	1-Apr
Slovakia	37.1	1-Apr
Sweden	45.0	15-Apr
Sugar cane		
Brazil	68.6	-
India	69.0	-
China	68.4	-
Mexico	74.2	-
Pakistan	46.5	-
Thailand	59.1	-
Australia	92.0	-
Colombia	86.2	-
Cuba	32.6	-
Indonesia	66.6	-
Philippines	70.9	-
South Africa	70.8	-

United States	78.7	-
Argentina	61.9	-
Bangladesh	41.0	-
Egypt	116.7	-
Guatemala	98.6	-
Peru	122.3	-
Venezuela	57.9	-
Viet Nam	49.4	-
		-
Maize		
United States	8.4	15-May
China	4.7	15-May
Argentina	5.3	1-Oct
Brazil	2.8	15-Apr
France	8.8	10-Feb
Mexico	2.4	1-May
India	1.8	15-May
Indonesia	2.7	1-Sep
Italy	9.5	1-Mar
Romania	3.0	1-Apr
Canada	7.1	15-Apr
Egypt	7.4	1-Nov
Germany	8.7	1-Apr
Nigeria	1.2	1-Oct
Philippines	1.7	1-May
South Africa	2.4	1-Apr
Spain	9.4	15-Jan
Thailand	3.5	1-Feb
Ukraine	2.9	15-Apr
Wheat		
China	3.8	15-Nov
India	2.6	1-May
United States	2.7	15-Nov
France	7.0	15-Nov
Russian Federation	1.6	1-May
Australia	1.9	15-Apr
Canada	2.2	15-Nov
Germany	7.4	15-Nov
Argentina	2.4	1-Oct
Pakistan	2.2	15-Apr
Turkey	2.0	15-Nov
Ukraine	2.5	15-Nov
Iran	1.7	15-Nov
Kazakhstan	0.9	15-Nov
United Kingdom	7.6	15-Nov
Czech Republic	4.4	15-Nov
Denmark	7.2	15-Nov
Egypt	6.1	15-Nov
Italy	3.1	15-Nov

Mexico	4.6	1-May
Poland	3.4	15-Nov
Romania	2.7	15-Nov
Spain	2.5	15-Nov
Syrian Arab Republic	2.0	15-Nov
Uzbekistan	2.5	15-Nov
Cassava		
Nigeria	10.7	1-Apr
Brazil	13.1	1-Apr
Thailand	15.9	1-Apr
Congo, Dem. Rep. of	8.1	1-Apr
Indonesia	12.4	1-Apr
Ghana	12.4	1-Apr
India	24.6	1-Apr
Tanzania	9.6	1-Nov
Mozambique	5.6	1-Nov
Angola	6.7	1-Oct
China	15.9	1-May
Paraguay	14.2	1-Oct
Uganda	10.9	1-Oct
Benin	10.6	1-Oct
Cameroon	12.0	1-Oct
Colombia	9.6	1-Oct
Cote d'Ivoire	5.4	1-Oct
Guinea	5.6	1-Oct
Madagascar	6.9	1-Sep
Malawi	9.6	1-Nov
Philippines	8.2	1-May
Viet Nam	10.4	1-May
Potato		
China	14.2	15-Apr
Russian Federation	10.3	1-May
India	17.7	15-May
Poland	17.4	15-Apr
United States	40.0	15-Apr
Ukraine	10.3	15-Apr
Germany	41.0	15-Apr
Belarus	11.5	15-Apr
France	38.4	15-Apr
Netherlands	44.2	15-Apr
Turkey	25.7	1-Apr
United Kingdom	40.2	15-Apr
Argentina	27.0	1-Nov
Bangladesh	11.7	15-Apr
Belgium-Luxemburg	27.7	15-Apr
Brazil	16.5	1-Oct
Canada	27.2	15-Apr
Colombia	16.2	1-Jan

Egypt	22.9	1-Nov
Iran	20.8	1-Mar
Italy	24.2	15-Mar
Japan	31.3	1-Mar
Kazakhstan	10.1	15-Mar
Lithuania	13.8	15-Apr
Malawi	11.2	1-Nov
Pakistan	14.9	1-Nov
Peru	10.6	1-Nov
Romania	13.3	1-Apr
South Africa	28.7	1-Apr
Spain	24.0	1-Dec
Paddy rice		
China	6.2	15-Jun
India	2.9	15-Jun
Indonesia	4.3	1-Oct
Bangladesh	3.1	15-Jun
Viet Nam	4.0	1-May
Thailand	2.5	1-May
Myanmar	3.2	1-Mar
Brazil	2.9	1-Oct
Japan	6.4	15-Mar
Philippines	2.9	1-May
Cambodia	1.9	1-Apr
Egypt	8.8	1-Nov
Korea	6.7	15-Mar
Nepal	2.5	15-May
Nigeria	1.4	1-Sep
Pakistan	2.9	1-Jun
United States	6.7	1-Mar
Barley		
Russian federation	1.6	15-Apr
Canada	2.9	15-Apr
Germany	5.9	20-Mar
France	6.1	20-Mar
Spain	2.6	1-Jan
Turkey	2.1	1-Mar
Australia	1.9	1-Nov
Ukraine	2.0	15-Apr
United Kingdom	5.5	15-Apr
United States	3.1	15-Apr
Denmark	5.2	15-Apr
China	2.9	15-Apr
Czech republic	3.7	1-Mar
Iran	1.5	1-Mar
Poland	3.0	15-Apr
Austria	4.5	15-Apr
Belarus	2.0	15-Apr

Bulgaria	2.7	1-Apr
Ethiopia	1.0	1-Mar
Finland	3.0	1-May
India	1.9	1-Jun
Ireland	6.4	1-Apr
Italy	3.5	15-Mar
Kazakhstan	1.0	1-Mar
Lithuania	2.2	15-Apr
Morocco	5.8	1-Jan
Romania	2.6	1-Apr
Sweden	4.0	1-Jun
Syria	0.6	1-Jan
Sorghum		
United States	4.1	1-Jun
India	0.8	1-Jun
Nigeria	1.1	1-Jun
Mexico	3.1	1-May
China	3.4	15-Apr
Sudan	0.6	1-Jun
Argentina	4.4	1-Oct
Australia	2.7	1-Sep
Burkina Faso	0.8	1-May
Ethiopia	1.2	1-Mar
Brazil	1.7	1-Oct
Cameroon	1.1	1-Nov
Chad	0.6	1-May
Egypt	5.6	1-Nov
France	6.1	1-Mar
Ghana	1.0	1-Apr
Mali	0.9	1-Jun
Niger	0.2	1-Jun
South Africa	2.6	1-Oct
Tanzania	0.9	1-Nov
Uganda	1.3	1-Nov
Venezuela	2.2	1-May
Yemen	1.0	1-Nov
Global average		
Rye		
Russian federation	1.5	15-Apr
Poland	2.2	15-Apr
Germany	5.4	15-Apr
Ukraine	1.7	15-Apr
Belarus	1.7	15-Apr
China	1.7	15-Jun
Denmark	5.1	15-Apr
Spain	1.5	15-Jan
Canada	2.0	1-Apr
Sweden	4.9	15-Apr

Turkey	4.1	15-Mar
France	4.4	20-Mar
Czech rep.	3.5	15-Apr
Austria	3.8	15-Apr
United States	1.7	1-Jan
Lithuania	2.1	15-Apr
Soybean		
United States	2.5	1-May
Brazil	2.4	1-May
Argentina	2.3	1-May
China	1.7	1-May
India	1.0	1-Jun
Canada	2.4	1-May
Paraguay	2.6	1-May
Bolivia	1.8	1-May
Indonesia	1.2	1-May
Italy	3.6	1-Apr
Rapeseed		
China	1.4	1-Mar
Canada	1.4	15-Apr
India	0.9	1-Jun
Germany	3.4	1-Apr
France	3.1	1-Apr
Australia	1.2	1-Nov
United Kingdom	2.9	1-Apr
Poland	2.7	1-Apr
Czech republic	2.6	1-Apr
United States	1.5	1-Apr
Bangladesh	0.7	1-Apr
Denmark	2.8	15-Apr
Pakistan	1.0	1-Dec
Jatropha[b]		
India	0.9	-
Indonesia	4.8	-
Nicaragua	4.8	-
Brazil	4.8	-

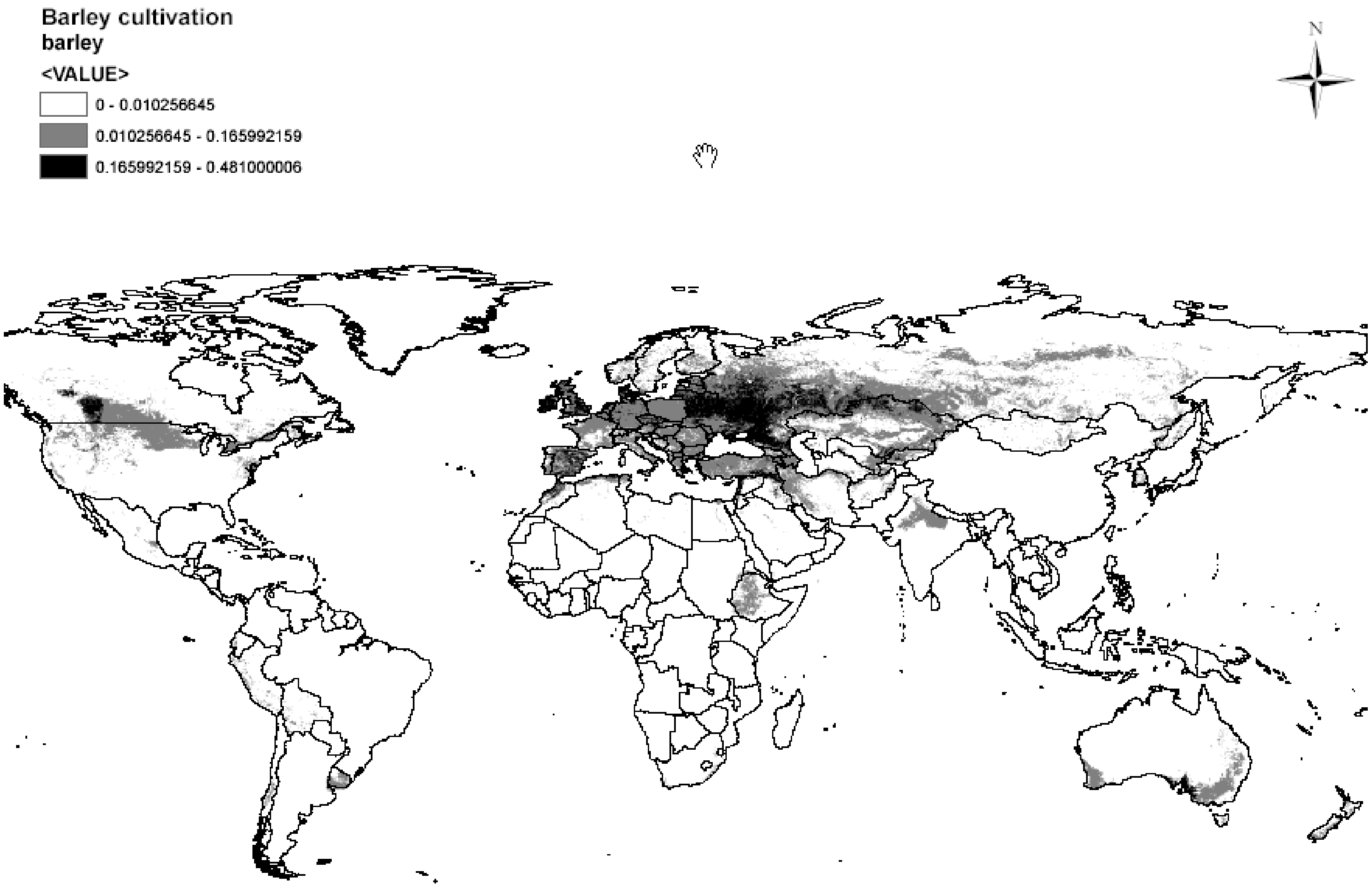
a. Source: FAO, 2008

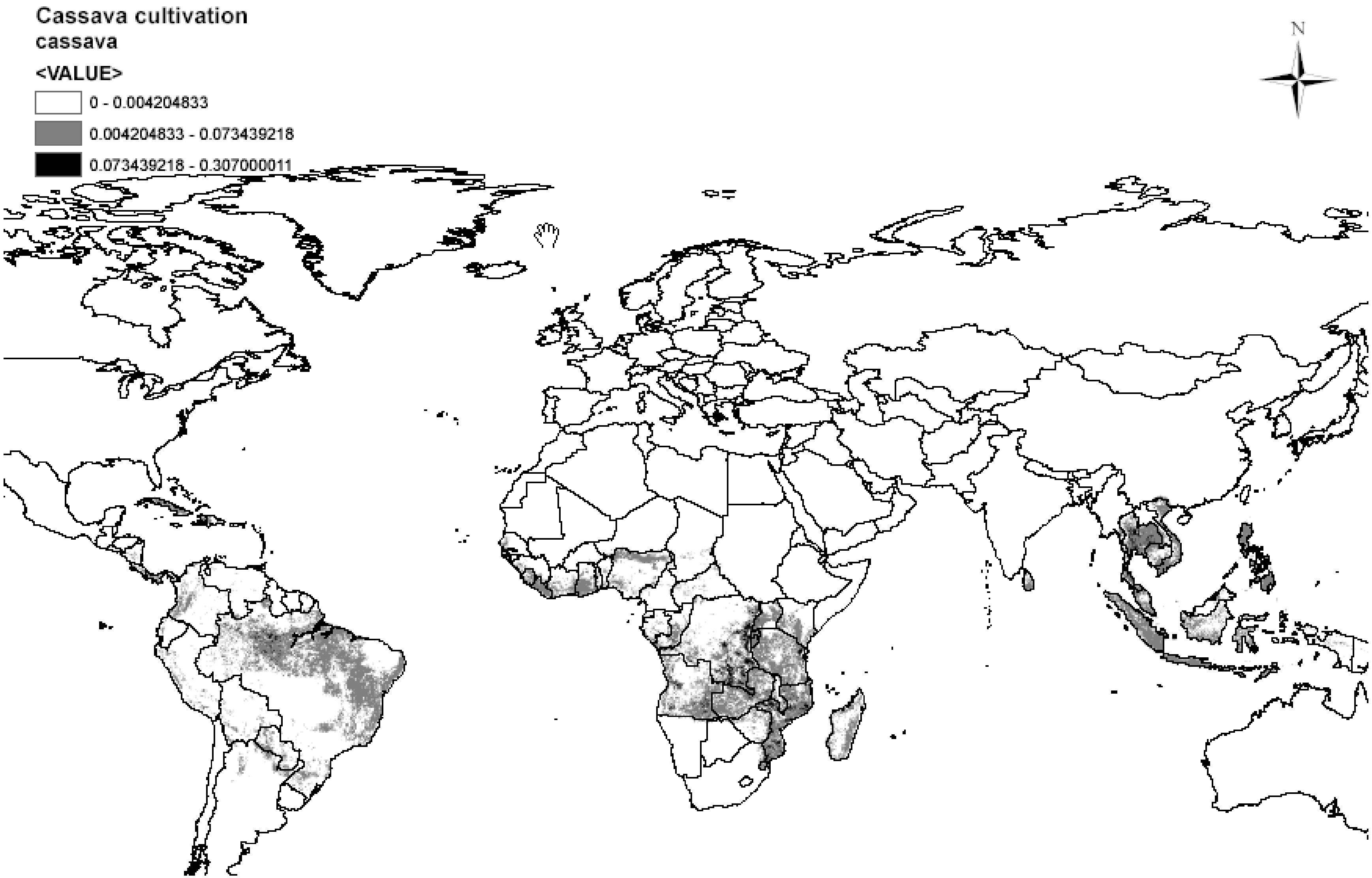
b. Planting dates are assumed based on climate data from Müller and Hennings (2000). The growing season begins when monthly mean maximum temperatures start to come above 10^0C, precipitation is available and global radiation is sufficient.

c. Source: Daey Ouwens et al., 2007; Fact Foundation, 2006

Appendix 5. Overview of global production locations for twelve main crops

Source: Center for Sustainability and the Global Environment of the University of Wisconsin-Madison, 2008.

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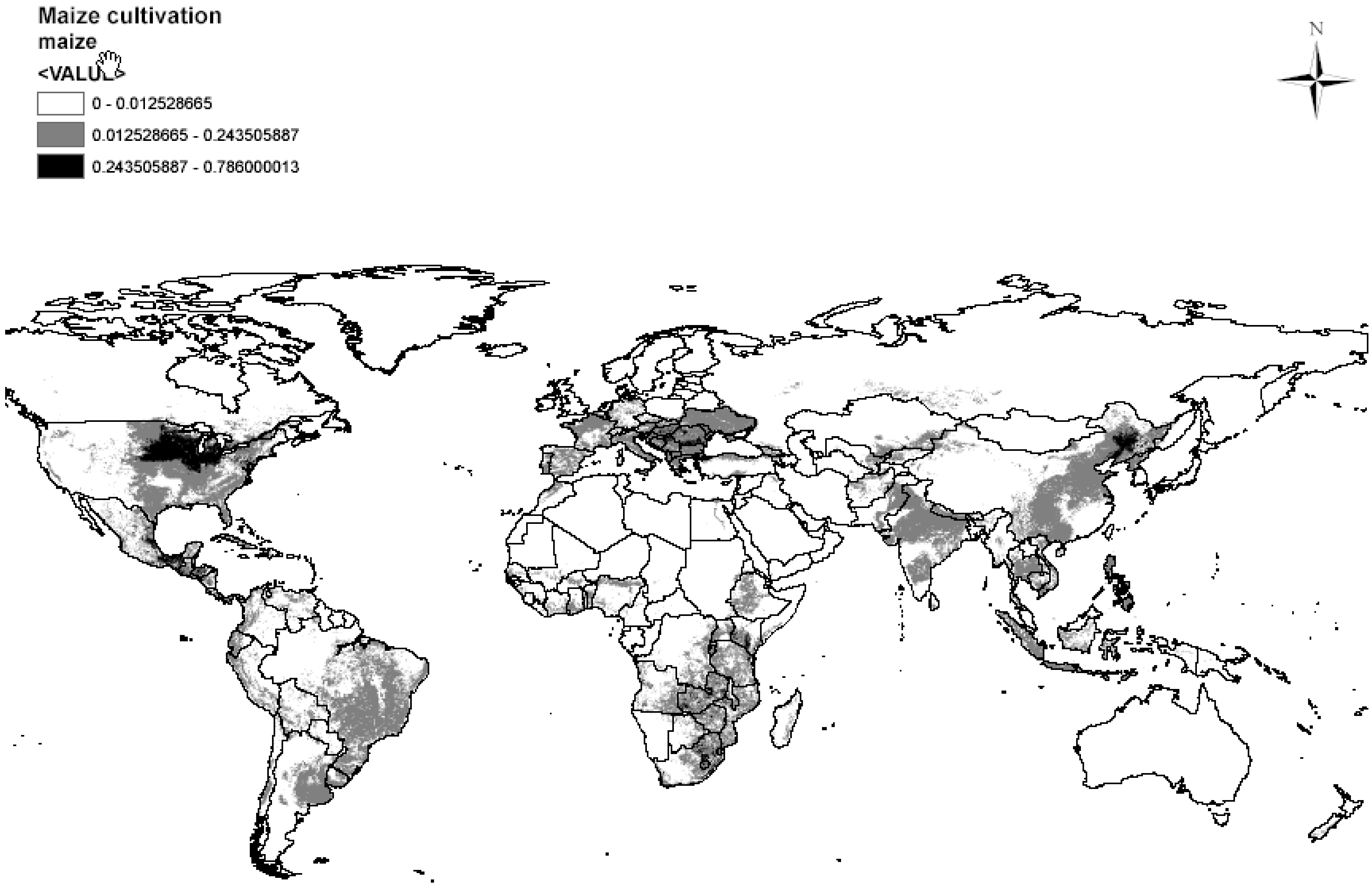
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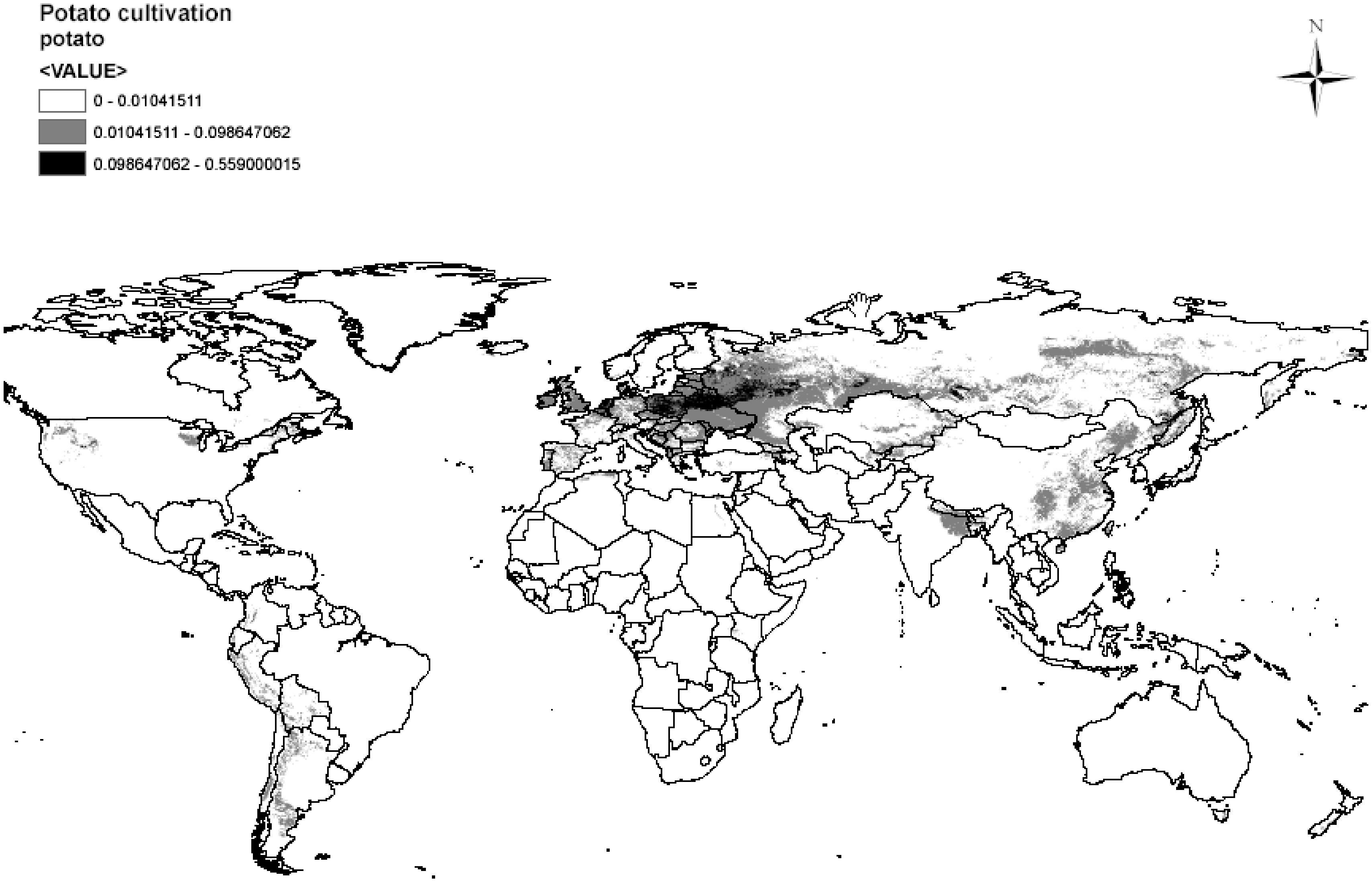
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potato
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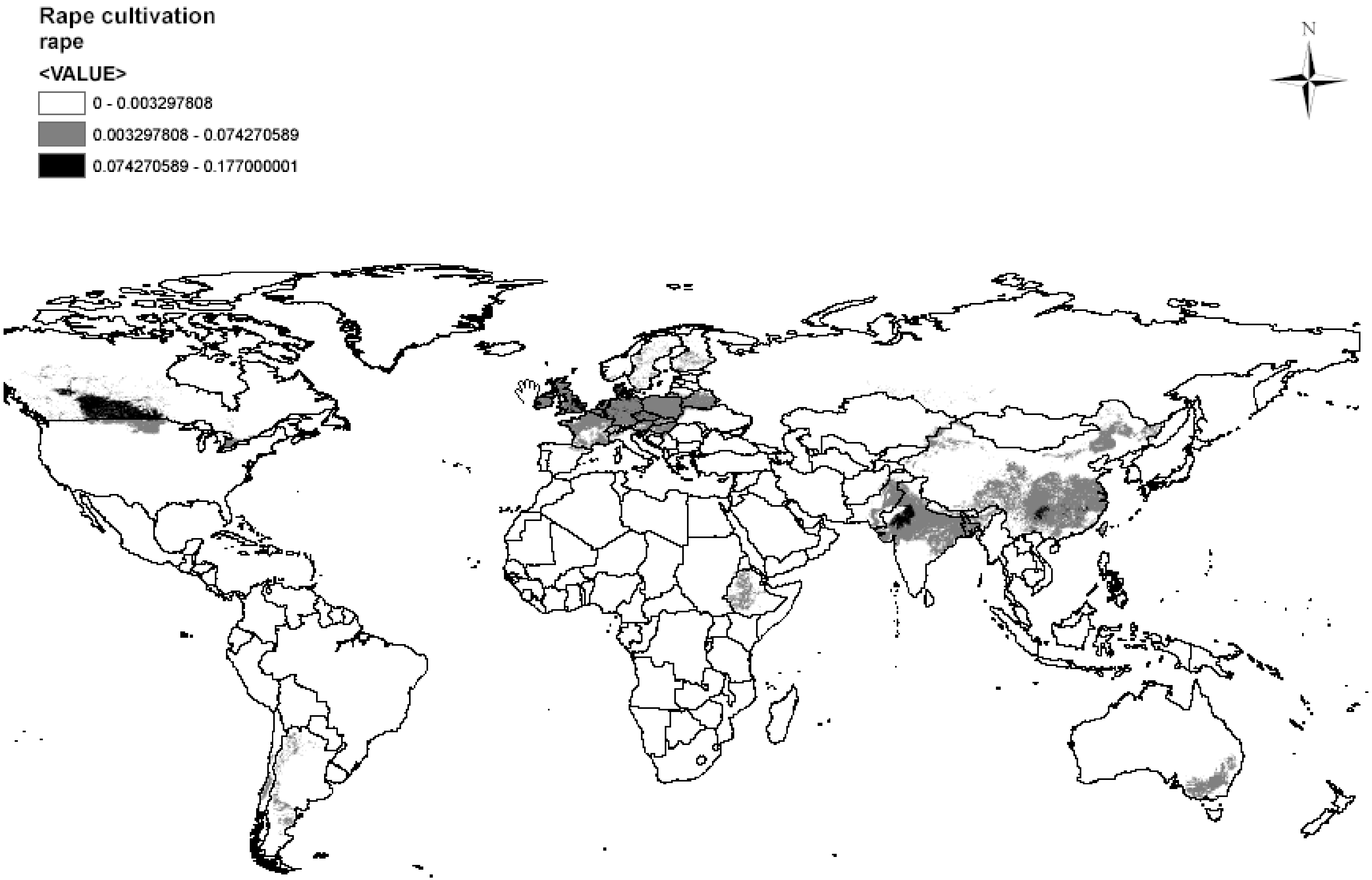
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rape
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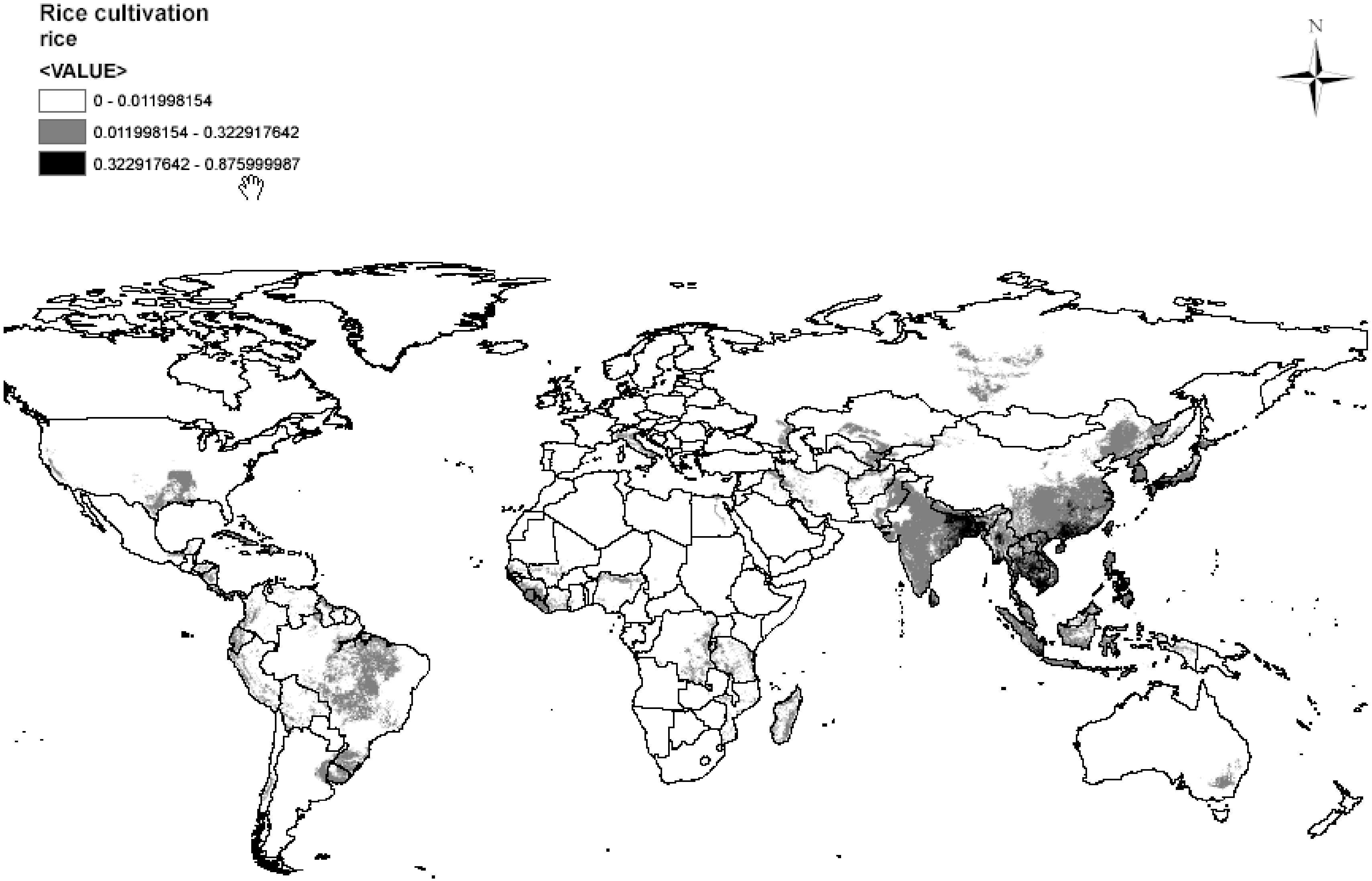
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rice
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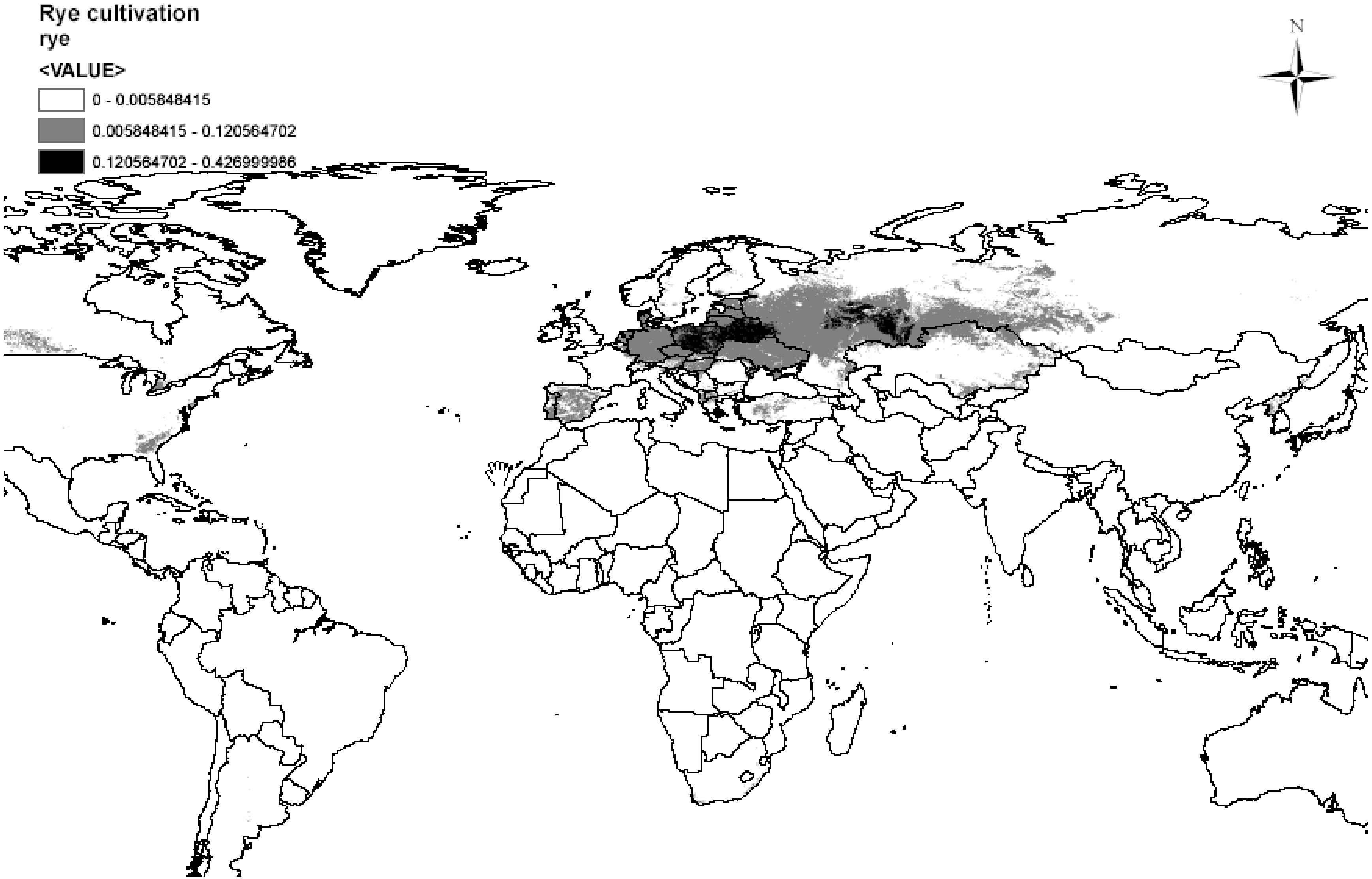
Rye cultivation
rye
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Sorghum cultivation
sorghum
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0.158745098 - 0.736000001
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Soy cultivation
soy
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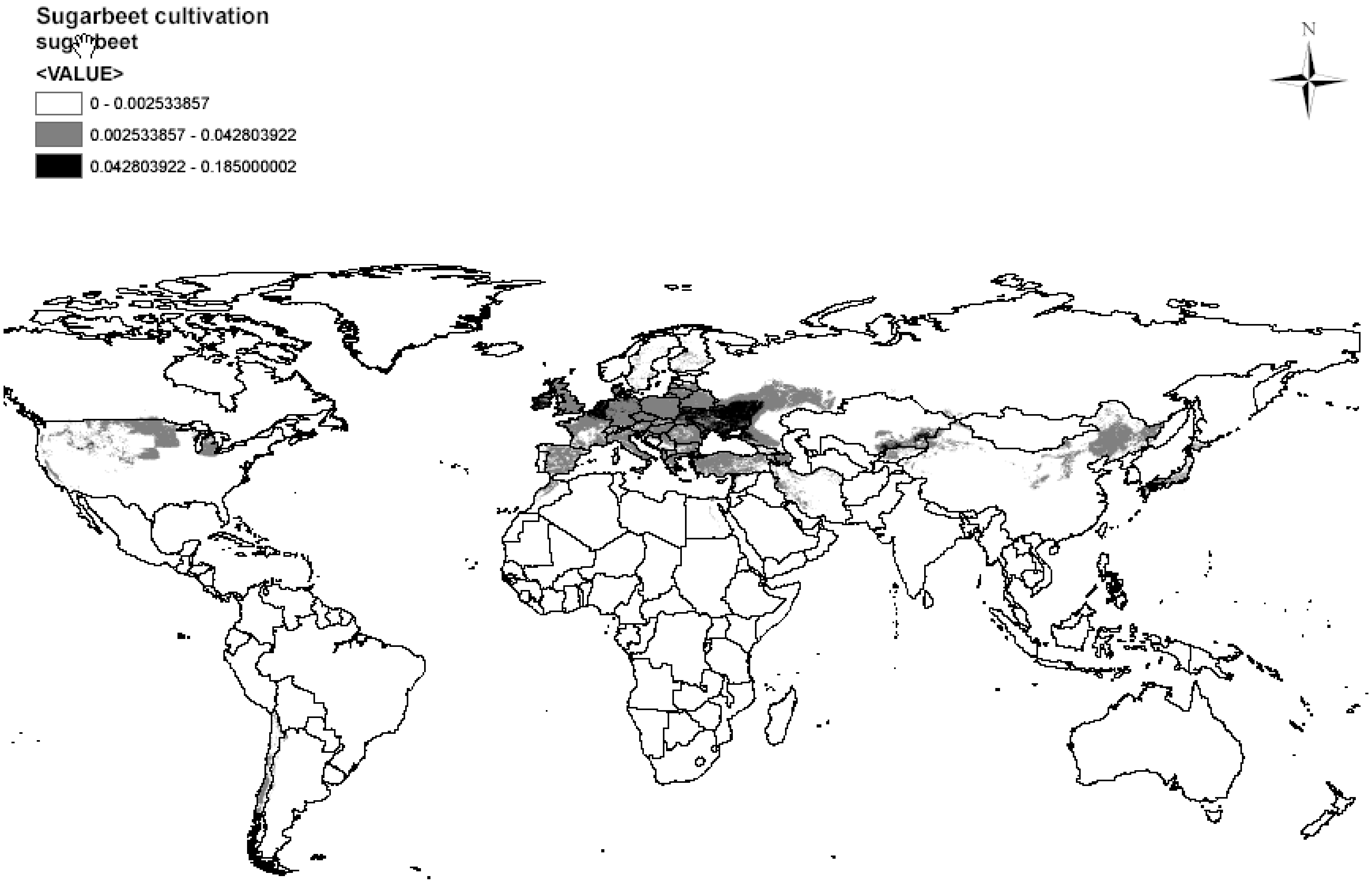
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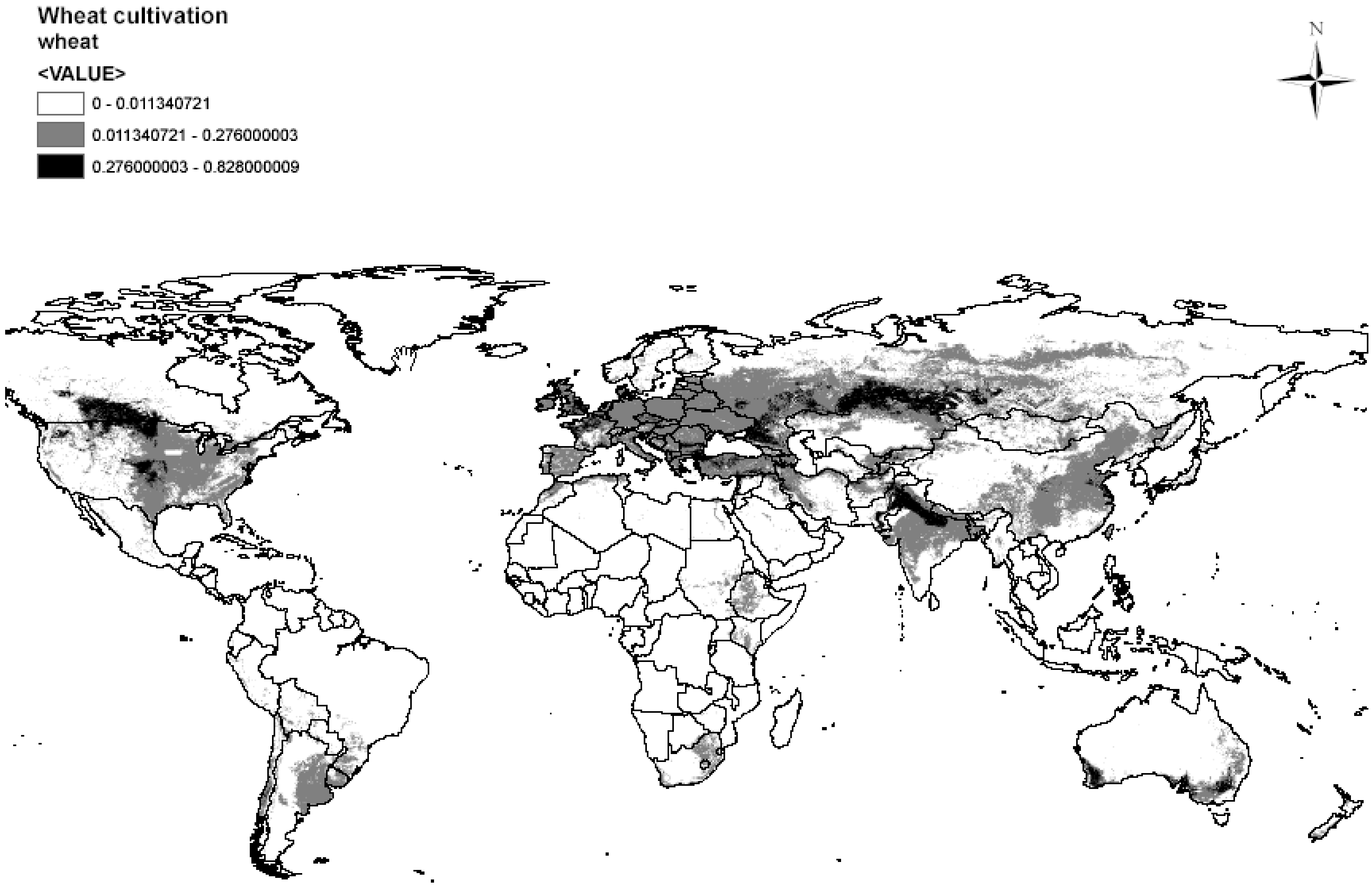
Wheat cultivation
wheat
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Appendix 6. Selected weather stations per crop per country

Source: Müller and Hennings (2000).

Crop	Country	Area	Weather station	Coordinates
Sugar beet	France	Nord-Pas de Calais, Picardie, Ile de France, Centre	Lille	50.73oN, 3.10oE
	United States	Minnesota	Minneapolis	44.88oN, 93.22oW
	Germany	Niedersachsen	Hamburg-Fuhlsbuttel	53.63oN, 10.00oE
	Turkey	West	Izmir	38.45oN, 27.25oN
	Ukraine	South	Kiev	50.40oN, 30.45oE
	China	North East	Harbin	45.75oN, 126.63oE
	Italy	Parma	Parma	44.80oN, 10.32oE
	Poland	whole country	Poznan	52.42oN, 16.83oE
	Russian federation	South	Wolgograd	48.70oN, 44.52oE
	United Kingdom	whole country	Cambridge	52.20oN, 0.13oW
	Netherlands	North	Eelde	53.13oN, 6.58oE
	South Africa	South	Porth Elizabeth	33.97oS, 25.60oE
	Belgium-Luxemburg	West	Lille	50.73oN, 3.10oE
	Iran	West	Kermanshah	34.35oN, 47.10oE
	Japan	South	Kagoshima	31.57oN, 130.55oE
	Austria	South East	Graz-Thalerhof	46.98oN, 15.45oE
	Belarus	Central	Minsk	53.87oN, 27.53oE
	Chile	South	Ushuaia	54.80oS, 68.32oW
	Czech republic	North East	Ostrava	49.85oN, 18.30oE
	Denmark	whole country	Odense	55.38oN, 10.45oE
	Egypt	North	Alexandria	31.20oN, 29.85oE
	Greece	whole country	Thessaloniki	40.65oN, 23.12oE
	Hungary	North West	Szombathely	47.25oN, 16.60oE
	Ireland	South West	Kilkenny	52.67oN, 7.27oW
	Moldova	whole country	Chisinau	47.02oN, 28.87oE
	Morocco	North	Rabat	34.05oN, 6.67oE
	Romania	East	La	47.17oN, 27.60oE
	Serbia	whole country	Belgrad	44.80oN, 20.45oE
	Slovakia	East	Presov	49.00oN, 21.25oE
	Sweden	South	Malmo	55.43oN, 13.05oE
Sugar cane	*Brazil*	Sao Paulo	Tres Lagoas	20.78oS, 51.70oW
	India	Uttar Pradesh	Kanpur	26.47oN, 80.35oE
	China	Guangxi, Guangdong	Guangzhou	23.00oN, 113.22oE
	Mexico	whole country	Monterry	25.67oN, 100.30oW
	Pakistan	Punjab	Lahore	31.58o N, 74.33o E
	Thailand	whole country	Nakhon Ratchasima	14.97oN, 102.12oE
	Australia	Queensland	Brisbane	27.47oS, 153.03oE
	Colombia	West	Guayaquil	2.20oS, 79.88oW
	Cuba	whole country	Santa Domingo	18.48oN, 69.90oW
	Indonesia	whole country	Djakarta	6.18oS, 106.83oE
	Philippines	whole country	Manila	14.58oN, 120.98oE

	South Africa	North East	Maputo	25.97oS, 32.60oE
	United States	Florida	Tampa	27.95oN, 82.45oW
	Argentina	East	Sarmiento	45.58oS, 69.13oW
	Bangladesh	whole country	Narayangani	23.62oN, 90.50oE
	Egypt	North	Alexandria	31.20oN, 29.85oE
	Guatemala	whole country	San Salvador	13.72oN, 89.20oW
	Peru	West	Tingo Maria	9.13oS, 75.95oW
	Venezuela	North	San fernando de Apure	7.88oN, 67.43oW
	Viet Nam	South	Saigon	10.78oN, 106.70oE
Maize	United States	Iowa, Illinois, Indiana	Des Moines	41.58oN, 93.62oW
	China	Jillin, Shandong, Heilongjiang	Changchun	43.87oN, 125.33oE
	Argentina	East	Rosario	32.92oS, 60.78oW
	Brazil	Rio Grande do Sul, Parana, Sao Paulo	Tres Lagoas	20.78oS, 51,7o W
	France	Aquitane	Bordeaux	44.83oN, 0.70oW
	Mexico	whole country	Monterry	25.67oN, 100.30oW
	India	North	Allahabad	25.28oN, 81.73oE
	Indonesia	whole country	Djakarta	6.18oS, 106.83oE
	Italy	whole country	Verona	45.43oN, 10.98oE
	Romania	Centre	Pleven	43.60oN, 24.58oE
	Canada	South	Toronto	43.67oN, 79.40oW
	Egypt	North	Alexandria	31.20oN, 29.85oE
	Germany	whole country	Soltau	53.00oN, 9.83oE
	Nigeria	South	Cotonou	6.35oN, 2.43oE
	Philippines	whole country	Manila	14.58oN, 120.98oE
	South Africa	South East	Cape Town	33.90oS, 18.53oE
	Spain	whole country	Sevilla	37.40oN, 6.00oW
	Thailand	whole country	Nakhon Ratchasima	14.97oN, 102.12oE
	Ukraine	Whole country	Charkow	49.93oN, 36.28oE
Wheat	China	Shandong, Henan	Xuzhou	34.28oN, 117.17oE
	India	North and North West	Patna	25.62oN, 85.17oE
	United States	Kansas	Dodge City	37.77oN, 99.97oW
	France	Centre	Paris	48.97oN, 2.45oE
	Russian Federation	Centre	Tobolsk	58.20oN, 69.23oE
	Australia	South West	Perth	31.95oS, 115.85oE
	Canada	Ontario	Regina	50.43oN, 104.67oW
	Germany	Bayern	Weissenburg	49.03oN, 10.97oE
	Argentina	East	Rosario	32.92oS, 60.78oW
	Pakistan	East	Lahore	31.58oN, 74.33oE
	Turkey	North	Zonguldak	41.45oN, 31.80oE
	Ukraine	whole country	Kiev	50.40oN, 30.45oE
	Iran	West	Kermanshah	34.35oN, 47.10oE
	Kazakhstan	whole country	Kzyl-Orda	44.77oN, 56.53oE
	United Kingdom	South East	Oxford	51.77oN, 1.27oW
	Czech Republic	Centre	Prague	50.08oN, 14.42oE
	Denmark	whole country	Odense	55.38oN, 10.45oE
	Egypt	North	Alexandria	31.20oN, 29.85oE
	Italy	whole country	Verona	45.43oN, 10.98oE
	Mexico	whole country	Monterry	25.67oN, 100.30oW

	Poland	whole country	Poznan	52.42oN, 16.83oE
	Romania	Centre	Pleven	43.60oN, 24.58oE
	Spain	whole country	Sevilla	37.40oN, 6.00oW
	Syrian Arab Republic	North	Dayer-Az-Zawr	35.35oN, 40.15oE
	Uzbekistan	whole country	Kzyl-Orda (Kas)	44.77oN, 56.53oE
Cassava	Nigeria	Sud	Lagos	6.45oN, 3.40oE
	Brazil	Centre and East	Manous	3.13oS, 60.02oW
	Thailand	East	Chiang Mai	18.78oN, 98.98oE
	Democratic R. of Congo	East	Eala (zaire)	0.05oN, 18.30o E
	Indonesia	whole country	Djakarta	6.18oS, 106.83oE
	Ghana		Tamale	9.42oN, 0.88oW
	India	South	Nuwara-Eliya	6.97oN, 80.77oE
	Tanzania	West	Morogo	6.85oS, 37.67oE
	Mozambique	whole country	Mossuril	14.95oS, 40.67oE
	Angola	whole country	Nova Lisboa	12.80oS, 15.75oE
	China	South	Nanning	22.80oN, 108.30oE
	Paraguay	whole country	Marischal Estigarriba	22.02oS, 60.60oW
	Uganda	whole country	Entebbe	0.05oN, 32.45oE
	Benin	whole country	Data Nigeria	
	Cameroon	South	Douala	4.02oN, 9.72oE
	Colombia	West	Manous (Brazil)	3.13oS, 60.02oW
	Cote d'Ivoire	South	Bouake	7.70oN, 5.00oW
	Guinea	Centre	Mandang	5.23oS, 145.75oE
	Madagascar	East	Antanarivo	18.90oS, 47.53oE
	Malawi	whole country	Blantyre	15.68oS, 34.97oE
	Philippines	whole country	Manila	14.58oN, 120.98oE
	Viet Nam	whole country	Saigon	10.78oN, 106.70oE
Potato	China	North east	Harbin	45.75oN, 126.63oE
	Russian Federation	Centre	Moskau	55.75oN, 37.57oE
	India	North east	Patna	25.62oN, 85.17oE
	Poland	whole country	Poznan	52.42oN, 16.83oE
	United States	North	Minneapolis	44.88oN, 93.22oW
	Ukraine	whole country	Kiev	50.40oN, 30.45oE
	Germany	whole country	Hamburg-Fuhlsbuttel	53.63oN, 10.00oE
	Belarus	whole country	Minsk	53.87oN, 27.53oE
	France	North west	Lille	50.73oN, 3.10oE
	Netherlands	North	Eelde	53.13oN, 6.58oE
	Turkey	North east	Trabzon	41.00oN, 39.72oE
	United Kingdom	whole country	Oxford	51.77oN, 1.27oW
	Argentina	South east	Rosario	32.92oS, 60.78oW
	Bangladesh	South	Narayangani	23.62oN, 90.50oE
	Belgium-Lux.	West	Lille	50.73oN, 3.10oE
	Brazil	South	Tres Lagoas	20.78oS, 51,7o W
	Canada	South	Toronto	43.67oN, 79.40oW
	Colombia	Centre	Manous (Brazil)	3.13oS, 60.02oW
	Egypt	North	Alexandria	31.20oN, 29.85oE
	Iran	West	Kermanshah	34.35oN, 47.10oE

	Italy	North	Verona	45.43oN, 10.98oE
	Japan	South	Kagoshima	31.57oN, 130.55oE
	Kazakhstan	West	Kzyl-Orda	44.77oN, 56.53oE
	Lithuania	whole country	Kaunas	54.88oN, 23.88oE
	Malawi	whole country	Blantyre	15.68oS, 34.97oE
	Pakistan	East	Lahore	31.58oN, 74.33oE
	Peru	whole country	Tingo Maria	9.13oS, 75.95oW
	Romania	South, East and West	Pleven	43.60oN, 24.58oE
	South Africa	South	Porth Elizabeth	33.97oS, 25.60oE
	Spain	whole country	Sevilla	37.40oN, 6.00oW
Paddy rice	China	Hunan, Guandong, Jiangxi	Wuhan	30.55oN, 114.28oE
	India	Andra Pradesh	Hyderabad	17.43oN, 78.45oE
	Indonesia	whole country	Djakarta	6.18oS, 106.83oE
	Bangladesh	North	Narayangany	23.62oN, 90.50oE
	Viet Nam	South	Saigon	10.78oN, 106.70oE
	Thailand	South	Nakhon Ratchasima	14.97oN, 102.12oE
	Myanmar	South	Rangun	16.77oN, 96.18oE
	Brazil	whole country	Barro do Corda	5.50oS, 45.27oW
	Japan	whole country	Nagasaki	32.73oN, 129.87oE
	Philippines	whole country	Manila	14.58oN, 120.98oE
	Cambodia	South	Phnom Penh	11.55oN, 104.92oE
	Egypt	North, along river Nile	Alexandria	31.20oN, 29.85oE
	Korea	whole country	Busan	35.10oN, 129.03oE
	Nepal	South	Patna (In)	25.62oN, 85.17oE
	Nigeria	South	Makurdi	7.70oN, 8.58oE
	Pakistan	East	Lahore	31.58oN, 74.33oE
	United States	Tennesse	Memphis	35.05oN, 89.98oW
Barley	Russian federation	Centre and South	Moskau	55.75oN, 37.57oE
	Canada	Alberta Saskatchewan	Edmonton (Alberta)	53.57oN, 113.52oW
	Germany	Bayern (spring barley)	Weissenburg	49.03oN, 10.97oE
	France	Centre, Bourgogne-France Comte	Paris	48.97oN, 2.45oE
	Spain	whole country	Sevilla	37.40oN, 6.00oW
	Turkey	whole country	Trabzon	41.00oN, 39.72oE
	Australia	South	Melbourne	37.82oS, 144.97oE
	Ukraine	whole country	Kiev	50.40oN, 30.45oE
	United Kingdom	East	Oxford	51.77oN, 1.27oW
	United States	North	Minneapolis	44.88oN, 93.22oW
	Denmark	whole country	Odense	55.38oN, 10.45oE
	China	North East	Harbin	45.75oN, 126.63oE
	Czech republic	North	Prague	50.08oN, 14.42oE
	Iran	West	Kermanshah	34.35oN, 47.10oE
	Poland	South East	Poznan	52.42oN, 16.83oE
	Austria	East	Graz-Thalerhof	46.98oN, 15.45oE
	Belarus	whole country	Minsk	53.87oN, 27.53oE
	Bulgaria	whole country	Pleven	43.60oN, 24.58oE
	Ethiopia	West	Jima	7.65oN, 36.85oE
	Finland	South	Helsinki	60.20oN, 24.92oE
	India	North	Patna	25.62oN, 85.17oE

	Ireland	whole country	Kilkenny	52.67oN, 7.27oW
	Italy	whole country	Verona	45.43oN, 10.98oE
	Kazakhstan	whole country	Kzyl-Orda	44.77oN, 56.53oE
	Lithuania	whole country	Kaunas	54.88oN, 23.88oE
	Morocco	North	Rabat	34.05oN, 6.67oW
	Romania	whole country	La	47.17oN, 27.60oE
	Sweden	Centre and South	Malmo	55.43oN, 13.05oE
	Syria	North	Dayer-Az-Zawr	35.35oN, 40.15oE
Sorghum	United States	Kansas	Dodge City	37.77oN, 99.97oW
	India	Centre	Indore	22.72oN, 75.90oE
	Nigeria	Northwest	Makurdi	7.70oN, 8.58oE
	Mexico	North east	Brownsville (US)	25.90oN, 97.43oW
	China	North East	Harbin	45.75oN, 126.63oE
	Sudan	North	Khartoum	15.60oN, 32.53oE
	Argentina	North East	Rosario	32.92oS, 60.78oW
	Australia	South East	Melbourne	37.82oS, 144.97oE
	Burkina Faso	South	Ouagadougou	12.37oN, 1.52oW
	Ethiopia	West	Jima	7.65oN, 36.85oE
	Brazil	South	Alegrete	29.77oS, 55.78oW
	Cameroon	South	Douala	4.02oN, 9.72oE
	Chad	West	Moundou	8.62oN, 16.07oE
	Egypt	North	Alexandria	31.20oN, 29.85oE
	France	South	Toulouse	43.62oN, 1.37oE
	Ghana		Tamale	9.42oN, 0.88oW
	Mali	South	Mopti	14.50oN, 4.20oW
	Niger	South	Zinder	13.80oN, 8.98oE
	South Africa	North east	Pietersburg	23.85oS, 29.45oE
	Tanzania	whole country	Morogo	6.85oS, 37.67oE
	Uganda	whole country	Entebbe	0.05oN, 32.45oE
	Venezuela	North	San Fernando de Apure	7.88oN, 67.43oW
	Yemen	West	Khormaksar	12.83oN, 45.02oE
Rye	Russian federation	Central	Moskau	55.75oN, 37.57oE
	Poland	Piotrkow, Radom, Siedice, Ostrol	Poznan	
	Germany	Brandenburg	Berlin-Dahlem	52.47oN, 13.30oE
	Ukraine	Central	Kiev	50.40oN, 30.45oE
	Belarus	Central	Minsk	53.87oN, 27.53oE
	China	North	Harbin	45.75oN, 126.63oE
	Denmark	whole country	Odense	55.38oN, 10.45oE
	Spain	whole country	Sevilla	37.40oN, 6.00oW
	Canada	South	Toronto	43.67oN, 79.40oW
	Sweden	South	Malmo	55.43oN, 13.05oE
	Turkey	Centre	Konya	37.85oN, 32.50oE
	France	Centre	Paris	48.97oN, 2.45oE
	Czech rep.	North East	Ostrava	49.85oN, 18.30oE
	Austria	South East	Graz-Thalerhof	46.98oN, 15.45oE
	United States	Georgia	Atlanta	33.65oN, 84.42oW
	Lithuania	whole country	Kaunas	54.88oN, 23.88oE

Rapeseed	China	Anhui, Hubei, Sichuan	Xi'an	34.25oN, 106.58oE
	Canada	Middle, South	Regina	50.43oN, 104.67oW
	India	Rajasthan, Gujarat, Uttar Pradesh	Jodhpur	26.30oN, 73.02oE
	Germany	Mecklenburg Vorpommern	Soltau	53.00oN, 9.83oE
	France	Champagne, Ardennes, Bourgogne, France Comte	Lille	50.73oN, 3.10oE
	Australia	Southeast	Melbourne	37.82oS, 144.97oE
	United Kingdom	East	Cromer	52.93oN, 1.28oE
	Poland	whole country	Poznan	52.42oN, 16.83oE
	Czech republic	East	Ostrava	49.85oN, 18.30oE
	United States	North Dakota	Bismarck	46.77oN, 100.75oW
	Bangladesh	South	Narayangani	23.62oN, 90.50oE
	Denmark	North and middle	Studsgard	56.08oN, 8.92oE
	Pakistan	East	Lahore	31.58oN, 74.33oE
Soybean	United States	Iowa, Illinois, Indiana	Des Moines	41.58oN, 93.62oW
	Brazil	Rio Grande do Sul, Parana	Tres Lagoas	20.78oS, 51.70oW
	Argentina	Northeast	Rosario	32.92oS, 60.78oW
	China	Heilonhjiang	Harbin	45.75oN, 126.63oE
	India	Centre	Indore	22.72oN, 75.90oE
	Canada	Centre South	Regina	50.43oN, 104.67oW
	Paraguay	whole country	Asuncion	25.27oS, 57.63oW
	Bolivia	west	Yacuiba	22.02oS, 63.72oW
	Indonesia	whole country	Djakarta	6.18oS, 106.83oE
	Italy	whole country	Verona	45.43oN, 10.98oE
Jatropha	India		Bangalore	12.95oN, 77.62oE
	Indonesia		Djakarta	6.18oS, 106.83oE
	Nicaragua		Managua	13.72oN, 89.20oW
	Brazil		Tres Lagoas	20.78oS, 51.70oW
	Guatemala		San Salvador	13.72oN, 89.20oW

Appendix 7. The contribution to global production per country for twelve main crops

	Contribution to global production
Sugar cane	
Brazil	0.27
India	0.23
China	0.06
Mexico	0.04
Pakistan	0.04
Thailand	0.04
Australia	0.03
Colombia	0.03
Cuba	0.03
Indonesia	0.02
Philippines	0.02
South Africa	0.02
United States	0.02
Argentina	0.01
Bangladesh	0.01
Egypt	0.01
Guatemala	0.01
Peru	0.01
Venezuela	0.01
Viet Nam	0.01
Rest	0.08
Maize	
United States	0.40
China	0.19
Argentina	0.06
Brazil	0.06
France	0.03
Mexico	0.03
India	0.02
Indonesia	0.02
Italy	0.02
Romania	0.02
Canada	0.01
Egypt	0.01
Germany	0.01
Nigeria	0.01
Philippines	0.01
South Africa	0.01
Spain	0.01
Thailand	0.01
Ukraine	0.01
Rest	0.06
Wheat	
China	0.18

India	0.12
United States	0.11
France	0.06
Russian Federation	0.06
Australia	0.04
Canada	0.04
Germany	0.04
Argentina	0.03
Pakistan	0.03
Turkey	0.03
Ukraine	0.03
Iran	0.02
Kazakhstan	0.02
United Kingdom	0.02
Czech Republic	0.01
Denmark	0.01
Egypt	0.01
Italy	0.01
Mexico	0.01
Poland	0.01
Romania	0.01
Spain	0.01
Syrian Arab Republic	0.01
Uzbekistan	0.01
Rest	0.07
Paddy rice	
China	0.33
India	0.22
Indonesia	0.08
Bangladesh	0.06
Viet Nam	0.05
Thailand	0.04
Myanmar	0.03
Brazil	0.02
Japan	0.02
Philippines	0.02
Cambodia	0.01
Egypt	0.01
Korea	0.01
Nepal	0.01
Nigeria	0.01
Pakistan	0.01
United States	0.01
Rest	0.06
Potato	
China	0.20
Russian Federation	0.11
India	0.07

Poland	0.07
United States	0.07
Ukraine	0.05
Germany	0.04
Belarus	0.02
France	0.02
Netherlands	0.02
Turkey	0.02
United Kingdom	0.02
Argentina	0.01
Bangladesh	0.01
Belgium-Luxemburg	0.01
Brazil	0.01
Canada	0.01
Colombia	0.01
Egypt	0.01
Iran	0.01
Italy	0.01
Japan	0.01
Kazakhstan	0.01
Lithuania	0.01
Malawi	0.01
Pakistan	0.01
Peru	0.01
Romania	0.01
South Africa	0.01
Spain	0.01
Rest	0.11
Sugar beet	
France	0.12
United States	0.11
Germany	0.10
Turkey	0.07
Ukraine	0.06
China	0.05
Italy	0.05
Poland	0.05
Russian federation	0.05
United Kingdom	0.04
Netherlands	0.03
South Africa	0.03
Belgium-Luxemburg	0.02
Iran	0.02
Japan	0.02
Austria	0.01
Belarus	0.01
Chile	0.01
Czech republic	0.01
Denmark	0.01

Egypt	0.01
Greece	0.01
Hungary	0.01
Ireland	0.01
Moldova	0.01
Morocco	0.01
Romania	0.01
Serbia	0.01
Slovakia	0.01
Sweden	0.01
Total	0.97
Rye	
Russian federation	0.25
Poland	0.23
Germany	0.21
Ukraine	0.06
Belarus	0.06
China	0.04
Denmark	0.02
Spain	0.01
Canada	0.01
Sweden	0.01
Turkey	0.01
France	0.01
Czech rep.	0.01
Austria	0.01
United States	0.01
Lithuania	0.01
Rest	0.04
Cassava	
Nigeria	0.19
Brazil	0.12
Thailand	0.10
Congo	0.09
Indonesia	0.09
Ghana	0.05
India	0.04
Tanzania	0.04
Mozambique	0.03
Angola	0.02
China	0.02
Paraguay	0.02
Uganda	0.02
Benin	0.01
Cameroon	0.01
Colombia	0.01
Cote d'Ivoire	0.01
Guinea	0.01

Madagascar	0.01
Malawi	0.01
Philippines	0.01
Viet Nam	0.01
Rest	0.08
Soybean	
United States	0.47
Brazil	0.20
Argentina	0.12
China	0.09
India	0.04
Canada	0.02
Paraguay	0.02
Bolivia	0.01
Indonesia	0.01
Italy	0.01
Rest	0.01
Barley	
Russian federation	0.11
Canada	0.09
Germany	0.09
France	0.07
Spain	0.06
Turkey	0.06
Australia	0.05
Ukraine	0.05
United Kingdom	0.05
United States	0.05
Denmark	0.03
China	0.02
Czech republic	0.02
Iran	0.02
Poland	0.02
Austria	0.01
Belarus	0.01
Bulgaria	0.01
Ethiopia	0.01
Finland	0.01
India	0.01
Ireland	0.01
Italy	0.01
Kazakhstan	0.01
Lithuania	0.01
Morocco	0.01
Romania	0.01
Sweden	0.01
Syria	0.01
Rest	0.07

Sorghum	
United States	0.23
India	0.13
Nigeria	0.12
Mexico	0.10
China	0.06
Sudan	0.06
Argentina	0.05
Australia	0.03
Burkina Faso	0.02
Ethiopia	0.02
Brazil	0.01
Cameroon	0.01
Chad	0.01
Egypt	0.01
France	0.01
Ghana	0.01
Mali	0.01
Niger	0.01
South Africa	0.01
Tanzania	0.01
Uganda	0.01
Venezuela	0.01
Yemen	0.01
Rest	0.05
Rapeseed	
China	0.27
Canada	0.19
India	0.14
Germany	0.10
France	0.09
Australia	0.04
United Kingdom	0.04
Poland	0.03
Czech republic	0.02
United States	0.02
Bangladesh	0.01
Denmark	0.01
Pakistan	0.01
Rest	0.03

Appendix 8. Crop water requirements and irrigation requirements

Crop	Country	Crop water requirement (mm/growth period)	Irrigation requirement (mm/growth period)
Sugar beet	France	476	219
	United States	696	356
	Germany	527	242
	Turkey	510	312
	Ukraine	732	489
	China	671	247
	Italy	622	375
	Poland	586	332
	Russian federation	828	684
	United Kingdom	509	288
	Netherlands	517	307
	Belgium-Luxemburg	498	256
	Iran	1035	913
	Japan	533	0
	Austria	450	52
	Belarus	587	294
	Chile	413	186
	Czech republic	495	162
	Denmark	483	235
	Egypt	454	302
	Greece	684	522
	Hungary	536	220
	Ireland	404	130
	Moldova	721	444
	Morocco	292	53
	Romania	748	493
	Serbia	743	450
	Slovakia	601	288
	Sweden	446	218
	Weighted global average	594	326
Sugar cane	Brazil	1581	662
	India	1893	1392
	China	1322	391
	Mexico	1507	971
	Pakistan	1411	1010
	Thailand	1631	756
	Australia	1499	684
	Colombia	1577	1195
	Cuba	1709	638
	Indonesia	1730	675
	Philippines	1648	632
	South Africa	1619	1038
	United States	1909	1303
	Argentina	1354	1294

	Bangladesh	1433	418
	Egypt	1946	1798
	Guatemala	1922	951
	Peru	1326	93
	Venezuela	1816	897
	Viet Nam	1651	575
	Weighted global average	1649	910
Maize	United States	656	314
	China	554	194
	Argentina	350	30
	Brazil	394	143
	France	374	186
	Mexico	573	291
	India	642	157
	Indonesia	525	117
	Italy	413	206
	Romania	525	313
	Canada	524	286
	Egypt	361	209
	Germany	414	184
	Nigeria	454	272
	Philippines	498	2
	South Africa	224	0
	Spain	383	216
	Thailand	528	280
	Ukraine	594	385
	Weighted global average	551	233
Wheat	China	655	365
	India	529	82
	United States	841	580
	France	488	260
	Russian Federation	340	144
	Australia	303	0
	Canada	495	203
	Germany	438	164
	Argentina	696	696
	Pakistan	166	130
	Turkey	445	172
	Ukraine	522	315
	Iran	868	546
	Kazakhstan	916	899
	United Kingdom	413	183
	Czech Republic	571	336
	Denmark	369	175
	Egypt	328	198
	Italy	457	186
	Mexico	514	257
	Poland	374	178

	Romania	433	205
	Spain	586	365
	Syrian Arab Republic	1020	890
	Uzbekistan	916	899
	Weighted global average	566	311
Cassava	Nigeria	619	0
	Brazil	799	339
	Thailand	724	67
	Congo, Dem. Rep. of	623	16
	Indonesia	623	16
	Ghana	769	80
	India	469	0
	Tanzania	743	181
	Mozambique	729	116
	Angola	685	0
	China	734	85
	Paraguay	806	287
	Uganda	796	166
	Benin	619	0
	Cameroon	621	203
	Colombia	799	339
	Cote d'Ivoire	776	476
	Guinea	708	0
	Madagascar	761	124
	Malawi	793	295
	Philippines	736	0
	Viet Nam	746	0
	Weighted global average	690	100
Potato	China	589	269
	Russian Federation	472	227
	India	605	65
	Poland	498	277
	United States	640	341
	Ukraine	504	270
	Germany	446	199
	Belarus	502	246
	France	419	212
	Netherlands	438	190
	Turkey	418	243
	United Kingdom	410	207
	Argentina	442	83
	Bangladesh	457	0
	Belgium-Luxemburg	419	212
	Brazil	584	100
	Canada	546	298
	Colombia	461	35
	Egypt	382	228
	Iran	766	630

	Italy	460	233
	Japan	457	0
	Kazakhstan	931	931
	Lithuania	441	185
	Malawi	485	20
	Pakistan	242	185
	Peru	416	0
	Romania	542	322
	South Africa	447	230
	Spain	204	41
	Weighted global average	519	231
Paddy rice	China	684	247
	India	895	433
	Indonesia	750	161
	Bangladesh	543	6
	Viet Nam	716	28
	Thailand	736	218
	Myanmar	704	283
	Brazil	627	220
	Japan	680	35
	Philippines	744	106
	Cambodia	824	329
	Egypt	558	404
	Korea	559	231
	Nepal	836	203
	Nigeria	906	648
	Pakistan	765	458
	United States	862	432
	Weighted global average	739	259
Barley	Russian federation	404	204
	Canada	408	203
	Germany	348	141
	France	378	216
	Spain	228	69
	Turkey	287	141
	Australia	517	314
	Ukraine	416	215
	United Kingdom	337	167
	United States	514	253
	Denmark	349	178
	China	487	214
	Czech republic	589	416
	Iran	589	416
	Poland	411	221
	Austria	373	103
	Belarus	418	202
	Bulgaria	436	245
	Ethiopia	355	15

	Finland	382	192
	India	470	28
	Ireland	287	98
	Italy	402	175
	Kazakhstan	654	651
	Lithuania	272	109
	Morocco	262	93
	Romania	491	306
	Sweden	324	157
	Syria	387	326
	Weighted global average	395	201
Sorghum	United States	671	409
	India	632	170
	Nigeria	403	0
	Mexico	604	357
	China	467	166
	Sudan	928	847
	Argentina	339	33
	Australia	429	224
	Burkina Faso	509	80
	Ethiopia	338	0
	Brazil	479	101
	Cameroon	321	140
	Chad	378	0
	Egypt	294	140
	France	344	162
	Ghana	402	48
	Mali	499	122
	Niger	494	135
	South Africa	492	230
	Tanzania	446	158
	Uganda	404	55
	Venezuela	387	0
	Yemen	413	413
	Weighted global average	552	248
Rye	Russian federation	393	183
	Poland	404	202
	Germany	375	177
	Ukraine	406	194
	Belarus	408	180
	China	348	104
	Denmark	342	159
	Spain	323	171
	Canada	433	220
	Sweden	312	146
	Turkey	470	372
	France	386	215
	Czech rep.	345	104

	Austria	368	93
	United States	346	79
	Lithuania	359	138
	Weighted global average	*388*	*181*
Soybean	United States	710	346
	Brazil	493	469
	Argentina	359	170
	China	589	227
	India	754	220
	Canada	659	450
	Paraguay	403	142
	Bolivia	531	360
	Indonesia	549	310
	Italy	519	270
	Weighted global average	601	330
Rapeseed	China	691	389
	Canada	726	472
	India	891	622
	Germany	504	195
	France	494	226
	Australia	664	361
	United Kingdom	453	206
	Poland	573	294
	Czech republic	492	219
	United States	789	522
	Bangladesh	546	0
	Denmark	443	128
	Pakistan	740	413
	Weighted global average	667	383
Jatropha	India	1986	1311
	Indonesia	1821	675
	Nicaragua	1908	1163
	Brazil	1559	566
	Guatemala	2046	1079
	Weighted global average	1864	959

Appendix 9. The water footprint per crop per country (m^3/ton)

Crop	Country	Water footprint in m^3 of water per ton of crop yield		
		Green water footprint	Blue water footprint	Total water footprint
Sugar beet	France	36	31	67
	United States	69	73	142
	Germany	52	44	95
	Turkey	48	76	125
	Ukraine	140	283	423
	China	161	93	254
	Italy	51	78	129
	Poland	69	90	159
	Russian federation	79	376	455
	United Kingdom	41	54	95
	Netherlands	37	54	91
	Belgium-Luxemburg	62	65	127
	Iran	45	338	383
	Japan	96	0	96
	Austria	63	8	72
	Belarus	109	109	218
	Chile	36	29	65
	Czech republic	76	37	113
	Denmark	46	44	89
	Egypt	33	65	97
	Greece	28	89	116
	Hungary	78	54	132
	Ireland	59	28	87
	Moldova	147	235	381
	Morocco	46	10	56
	Romania	126	244	370
	Serbia	84	129	214
	Slovakia	84	78	162
	Sweden	51	48	99
	Weighted global average	*69*	*100*	*169*
Sugar cane	Brazil	134	97	230
	India	73	202	274
	China	136	57	193
	Mexico	72	131	203
	Pakistan	86	217	303
	Thailand	148	128	276
	Australia	89	74	163
	Colombia	44	139	183
	Cuba	329	196	524
	Indonesia	158	101	260
	Philippines	143	89	232
	South Africa	82	147	229
	United States	77	166	243

	Argentina	10	209	219
	Bangladesh	248	102	350
	Egypt	13	154	167
	Guatemala	98	96	195
	Peru	101	8	108
	Venezuela	159	155	314
	Viet Nam	218	116	334
	Weighted global average	*114*	*136*	*250*
Maize	United States	408	374	781
	China	767	412	1179
	Argentina	604	57	660
	Brazil	898	510	1408
	France	214	212	425
	Mexico	1175	1213	2388
	India	2694	872	3567
	Indonesia	1511	433	1944
	Italy	218	217	435
	Romania	708	1043	1751
	Canada	335	403	738
	Egypt	205	282	488
	Germany	264	211	476
	Nigeria	1517	2267	3783
	Philippines	2915	14	2929
	South Africa	933	0	933
	Spain	178	230	407
	Thailand	709	800	1509
	Ukraine	721	1328	2048
	Weighted global average	*675*	*445*	*1120*
Wheat	China	761	961	1722
	India	1719	315	2035
	United States	966	2148	3114
	France	326	371	697
	Russian Federation	1225	900	2125
	Australia	1595	0	1595
	Canada	1327	923	2250
	Germany	370	222	592
	Argentina	0	2900	2900
	Pakistan	164	591	755
	Turkey	1365	860	2225
	Ukraine	828	1260	2088
	Iran	1894	3212	5106
	Kazakhstan	189	9989	10178
	United Kingdom	302	241	544
	Czech Republic	534	764	1298
	Denmark	269	243	513
	Egypt	213	325	538
	Italy	874	600	1474
	Mexico	559	559	1117

	Poland	576	524	1100
	Romania	844	759	1604
	Spain	884	1460	2344
	Syrian Arab Republic	650	4450	5100
	Uzbekistan	68	3596	3664
	Weighted global average	*899*	*1246*	*2145*
Cassava	Nigeria	578	0	578
	Brazil	351	259	610
	Thailand	413	42	455
	Congo, Dem. Rep. of	749	20	769
	Indonesia	490	13	502
	Ghana	556	65	620
	India	191	0	191
	Tanzania	585	189	774
	Mozambique	1095	207	1302
	Angola	1022	0	1022
	China	408	53	462
	Paraguay	365	202	568
	Uganda	578	152	730
	Benin	584	0	584
	Cameroon	348	169	518
	Colombia	479	353	832
	Cote d'Ivoire	556	881	1437
	Guinea	1264	0	1264
	Madagascar	923	180	1103
	Malawi	519	307	826
	Philippines	898	0	898
	Viet Nam	717	0	717
	Weighted global average	*557*	*93*	*650*
Potato	China	225	189	415
	Russian Federation	238	220	458
	India	305	37	342
	Poland	127	159	286
	United States	75	85	160
	Ukraine	227	262	489
	Germany	60	49	109
	Belarus	223	214	437
	France	54	55	109
	Netherlands	56	43	99
	Turkey	68	95	163
	United Kingdom	50	51	102
	Argentina	133	31	164
	Bangladesh	391	0	391
	Belgium-Lux.	75	77	151
	Brazil	293	61	354
	Canada	91	110	201
	Colombia	263	22	285
	Egypt	67	100	167

	Iran	65	303	368
	Italy	94	96	190
	Japan	146	0	146
	Kazakhstan	0	922	922
	Lithuania	186	134	320
	Malawi	415	18	433
	Pakistan	38	124	162
	Peru	392	0	392
	Romania	165	242	408
	South Africa	76	80	156
	Spain	68	17	85
	Weighted global average	*176*	*143*	*319*
Paddy rice	China	705	398	1103
	India	1593	1493	3086
	Indonesia	1370	374	1744
	Bangladesh	1732	19	1752
	Viet Nam	1720	70	1790
	Thailand	2072	872	2944
	Myanmar	1316	884	2200
	Brazil	1403	759	2162
	Japan	1008	55	1063
	Philippines	2200	366	2566
	Cambodia	2605	1732	4337
	Egypt	175	459	634
	Korea	490	345	834
	Nepal	2532	812	3344
	Nigeria	1843	4629	6471
	Pakistan	1059	1579	2638
	United States	642	645	1287
	Weighted global average	*1277*	*736*	*2013*
Barley	Russian federation	1250	1275	2525
	Canada	707	700	1407
	Germany	351	239	590
	France	266	354	620
	Spain	612	265	877
	Turkey	695	671	1367
	Australia	1068	1653	2721
	Ukraine	1005	1075	2080
	United Kingdom	309	304	613
	United States	842	816	1658
	Denmark	329	342	671
	China	941	738	1679
	Czech republic	468	1124	1592
	Iran	1153	2773	3927
	Poland	633	737	1370
	Austria	600	229	829
	Belarus	1080	1010	2090
	Bulgaria	707	907	1615

	Ethiopia	3400	150	3550
	Finland	633	640	1273
	India	2326	147	2474
	Ireland	295	153	448
	Italy	649	500	1149
	Kazakhstan	30	6510	6540
	Lithuania	741	495	1236
	Morocco	291	160	452
	Romania	712	1177	1888
	Sweden	418	393	810
	Syria	1017	5433	6450
	Weighted global average	*750*	*870*	*1620*
Sorghum	United States	639	998	1637
	India	5775	2125	7900
	Nigeria	3664	0	3664
	Mexico	797	1152	1948
	China	885	488	1374
	Sudan	1350	14117	15467
	Argentina	695	75	770
	Australia	759	830	1589
	Burkina Faso	5363	1000	6363
	Ethiopia	2817	0	2817
	Brazil	2224	594	2818
	Cameroon	1645	1273	2918
	Chad	6300	0	6300
	Egypt	275	250	525
	France	298	266	564
	Ghana	3540	480	4020
	Mali	4189	1356	5544
	Niger	17950	6750	24700
	South Africa	1008	885	1892
	Tanzania	3200	1756	4956
	Uganda	2685	423	3108
	Venezuela	1759	0	1759
	Yemen	0	4130	4130
	Weighted global average	*2371*	*1812*	*4183*
Rye	Russian federation	1400	1220	2620
	Poland	918	918	1836
	Germany	367	328	694
	Ukraine	1247	1141	2388
	Belarus	1341	1059	2400
	China	1435	612	2047
	Denmark	359	312	671
	Spain	1013	1140	2153
	Canada	1065	1100	2165
	Sweden	339	298	637
	Turkey	239	907	1146
	France	389	489	877

	Czech rep.	689	297	986
	Austria	724	245	968
	United States	1571	465	2035
	Lithuania	1052	657	1710
	Weighted global average	*964*	*832*	*1796*
Soybean	United States	1456	1384	2840
	Brazil	100	1954	2054
	Argentina	822	739	1561
	China	2129	1335	3465
	India	5340	2200	7540
	Canada	871	1875	2746
	Paraguay	1004	546	1550
	Bolivia	950	2000	2950
	Indonesia	1992	2583	4575
	Italy	692	750	1442
	Weighted global average	*1298*	*1455*	*2753*
Rapeseed	China	2157	2779	4936
	Canada	1814	3371	5186
	India	2989	6911	9900
	Germany	909	574	1482
	France	865	729	1594
	Australia	2525	3008	5533
	United Kingdom	852	710	1562
	Poland	1033	1089	2122
	Czech republic	1050	842	1892
	United States	1780	3480	5260
	Bangladesh	7800	0	7800
	Denmark	1125	457	1582
	Pakistan	3270	4130	7400
	Weighted global average	*1924*	*2860*	*4784*
Jatropha	India	7385	14344	21729
	Indonesia	2368	1395	3763
	Nicaragua	1540	2404	3943
	Brazil	2052	1170	3222
	Guatemala	1998	2230	4228
	Weighted global average	*3068*	*4309*	*7377*

Appendix 10. The water footprint of heat from biomass for the main producing countries (m^3/GJ)

Crop	Country	Water footprint in m^3 water per GJ thermal energy		
		Green water footprint	Blue water footprint	Total water footprint
Sugar beet	Morocco	8	2	10
	Chile	6	5	11
	France	6	5	12
	Austria	11	2	12
	Ireland	10	5	15
	Denmark	8	8	16
	Netherlands	6	9	16
	Germany	9	8	17
	United Kingdom	7	9	17
	Japan	17	0	17
	Egypt	6	11	17
	Sweden	9	8	17
	Czech republic	13	6	20
	Greece	5	15	20
	Turkey	8	13	22
	Belgium-Luxemburg	11	11	22
	Italy	9	14	22
	Hungary	14	9	23
	United States	12	13	25
	Poland	12	16	27
	Slovakia	15	14	28
	Serbia	15	22	37
	Belarus	19	19	38
	China	28	16	44
	Romania	22	42	64
	Moldova	25	41	66
	Iran	8	59	66
	Ukraine	24	49	73
	Russian federation	14	65	79
	Weighted global average	11	16	27
Sugar cane	Peru	13	1	14
	Australia	11	9	21
	Egypt	2	20	21
	Colombia	6	18	23
	China	17	7	25
	Guatemala	13	12	25
	Mexico	9	17	26
	Argentina	1	27	28
	South Africa	10	19	29
	Brazil	17	12	29
	Philippines	18	11	30
	United States	10	21	31

	Indonesia	20	13	33
	India	9	26	35
	Thailand	19	16	35
	Pakistan	11	28	38
	Venezuela	20	20	40
	Viet Nam	28	15	42
	Bangladesh	31	13	44
	Cuba	42	25	67
	Weighted global average	15	17	32
Maize	Spain	5	6	11
	France	6	6	11
	Italy	6	6	12
	Germany	7	6	13
	Egypt	6	8	13
	Argentina	16	2	18
	Canada	9	11	20
	United States	11	10	21
	South Africa	25	0	25
	China	21	11	32
	Brazil	24	14	38
	Thailand	19	22	41
	Romania	19	28	47
	Indonesia	41	12	52
	Ukraine	19	36	55
	Mexico	32	33	64
	Philippines	78	0	79
	India	72	24	96
	Nigeria	41	61	102
	Weighted global average	18	12	30
Wheat	Denmark	7	6	13
	Egypt	5	8	14
	United Kingdom	8	6	14
	Germany	9	6	15
	France	8	9	18
	Pakistan	4	15	19
	Poland	15	13	28
	Mexico	14	14	29
	Czech Republic	14	20	33
	Italy	22	15	38
	Australia	41	0	41
	Romania	22	19	41
	China	19	26	44
	India	44	8	52
	Ukraine	21	32	54
	Russian Federation	31	23	54
	Turkey	35	22	57
	Canada	34	24	58
	Spain	23	37	60

	Argentina	0	74	74
	United States	25	55	80
	Uzbekistan	2	92	94
	Syrian Arab Republic	17	114	131
	Iran	49	82	131
	Kazakhstan	5	256	261
	Weighted global average	23	32	55
Cassava	Nigeria	26	0	26
	Brazil	56	6	62
	Thailand	56	7	63
	Congo, Dem. Rep. of	67	2	68
	Indonesia	47	23	70
	Ghana	50	28	77
	India	79	0	79
	Tanzania	80	0	80
	Mozambique	48	35	83
	Angola	76	9	84
	China	98	0	98
	Paraguay	79	21	100
	Uganda	102	3	105
	Benin	80	26	105
	Cameroon	71	42	113
	Colombia	65	48	113
	Cote d'Ivoire	122	0	122
	Guinea	140	0	140
	Madagascar	126	25	150
	Malawi	173	0	173
	Philippines	149	28	177
	Viet Nam	76	120	196
	Weighted global average	76	13	89
Potato	Spain	13	3	16
	Netherlands	11	8	19
	United Kingdom	10	10	20
	Germany	12	9	21
	France	10	11	21
	Japan	28	0	28
	Belgium-Lux.	14	15	29
	South Africa	14	15	30
	United States	14	16	31
	Turkey	13	18	31
	Pakistan	7	24	31
	Argentina	25	6	31
	Egypt	13	19	32
	Italy	18	18	36
	Canada	17	21	38
	Poland	24	30	55
	Colombia	50	4	55
	Lithuania	36	26	62

	India	59	7	66
	Brazil	57	12	68
	Iran	13	58	71
	Bangladesh	75	0	75
	Peru	76	0	76
	Romania	32	46	78
	China	43	36	80
	Malawi	80	3	83
	Belarus	43	41	84
	Russian Federation	46	42	88
	Ukraine	44	50	94
	Kazakhstan	0	177	177
	Weighted global average	33	27	60
Paddy rice	Egypt	4	12	16
	Korea	12	9	21
	Japan	25	1	27
	China	18	10	28
	United States	16	16	32
	Indonesia	35	9	44
	Bangladesh	44	0	44
	Viet Nam	43	2	45
	Brazil	35	19	54
	Myanmar	33	22	55
	Philippines	55	9	65
	Pakistan	27	40	66
	Thailand	52	22	74
	India	40	38	78
	Nepal	64	20	84
	Cambodia	66	44	109
	Nigeria	46	117	163
	Weighted global average	28	21	48
Barley	Russian federation	32	33	65
	Canada	18	18	36
	Germany	9	6	15
	France	7	9	16
	Spain	16	7	23
	Turkey	18	17	35
	Australia	27	43	70
	Ukraine	26	28	53
	United Kingdom	8	8	16
	United States	22	21	43
	Denmark	8	9	17
	China	24	19	43
	Czech republic	12	29	41
	Iran	30	71	101
	Poland	16	19	35
	Austria	15	6	21
	Belarus	28	26	54

	Bulgaria	18	23	41
	Ethiopia	87	4	91
	Finland	16	2	33
	India	60	4	64
	Ireland	8	4	12
	Italy	17	13	29
	Kazakhstan	1	167	168
	Lithuania	19	13	32
	Morocco	8	4	12
	Romania	18	30	49
	Sweden	11	10	21
	Syria	26	140	166
	Weighted global average	20	22	42
Sorghum	Egypt	7	6	13
	France	8	7	14
	Argentina	18	2	20
	China	23	12	35
	Australia	19	21	41
	United States	16	26	42
	Venezuela	45	0	45
	South Africa	26	23	49
	Mexico	20	30	50
	Ethiopia	72	0	72
	Brazil	57	15	72
	Cameroon	42	33	75
	Uganda	69	11	80
	Nigeria	94	0	94
	Ghana	91	12	103
	Yemen	0	106	106
	Tanzania	82	45	127
	Mali	107	35	142
	Chad	162	0	162
	Burkina Faso	138	26	163
	India	148	55	203
	Sudan	35	362	397
	Niger	461	173	634
	Weighted global average	61	47	107
Rye	Sweden	9	8	16
	Denmark	9	8	17
	Germany	9	8	18
	France	10	13	22
	Austria	18	6	25
	Czech rep.	18	8	25
	Turkey	6	23	29
	Lithuania	27	17	44
	Poland	23	23	47
	United States	40	12	52
	China	37	16	52

	Spain	26	29	55
	Canada	27	28	55
	Ukraine	32	29	61
	Belarus	34	27	61
	Russian federation	36	31	67
	Weighted global average	25	21	46
Soybean	India	216	89	305
	Indonesia	81	104	185
	China	86	54	140
	Bolivia	38	81	119
	United States	59	56	115
	Canada	35	76	111
	Brazil	4	79	83
	Argentina	33	30	63
	Paraguay	41	22	63
	Italy	28	30	58
	Weighted global average	46	56	102
Rapeseed	India	141	326	468
	Bangladesh	368	0	368
	Pakistan	155	195	350
	Australia	119	142	261
	United States	84	165	249
	Canada	86	159	245
	China	102	131	233
	Poland	49	51	101
	Czech republic	50	40	89
	France	41	34	75
	Denmark	53	22	75
	United Kingdom	40	34	74
	Germany	43	27	70
	Weighted global average	91	135	226
Jatropha	Brazil	65	37	102
	Indonesia	75	44	119
	Nicaragua	49	76	125
	Guatemala	97	136	234
	India	234	454	689
	Weighted global average	97	136	234

Appendix 11. The water footprint of electricity from biomass for the main producing countries (m^3/GJ)

		Water footprint in m^3 water per GJ electricity		
Crop	Country	Green water footprint	Blue water footprint	Total water footprint
Sugar beet	Morocco	14	3	17
	Chile	11	9	19
	France	11	9	20
	Austria	19	3	21
	Ireland	17	8	26
	Denmark	14	13	26
	Netherlands	11	16	27
	Germany	15	13	28
	United Kingdom	12	16	28
	Japan	28	0	28
	Egypt	9	19	29
	Sweden	15	14	29
	Czech republic	22	11	33
	Greece	8	26	34
	Turkey	14	23	37
	Belgium-Luxemburg	18	19	38
	Italy	15	23	38
	Hungary	23	16	39
	United States	20	21	42
	Poland	20	26	46
	Slovakia	25	23	48
	Serbia	25	38	63
	Belarus	32	32	64
	China	47	27	75
	Romania	37	72	109
	Moldova	43	69	112
	Iran	13	99	113
	Ukraine	41	83	125
	Russian federation	23	110	134
	Weighted global average	*19*	*27*	*46*
Sugar cane	Peru	22	2	23
	Australia	19	16	35
	Egypt	3	33	36
	Colombia	10	30	39
	China	29	12	42
	Guatemala	21	21	42
	Mexico	16	28	44
	Argentina	2	45	47
	South Africa	18	32	49
	Brazil	29	21	50
	Philippines	31	19	50
	United States	17	36	52

	Indonesia	34	22	56
	India	16	43	59
	Thailand	32	27	59
	Pakistan	18	47	65
	Venezuela	34	33	67
	Viet Nam	47	25	72
	Bangladesh	53	22	75
	Cuba	71	42	113
	Weighted global average	*25*	*29*	*54*
Maize	Spain	8	10	19
	France	10	10	19
	Italy	10	10	20
	Germany	12	10	22
	Egypt	9	13	22
	Argentina	27	3	30
	Canada	15	18	34
	United States	19	17	36
	South Africa	42	0	42
	China	35	19	54
	Brazil	41	23	64
	Thailand	32	37	69
	Romania	32	48	80
	Indonesia	69	20	89
	Ukraine	33	61	94
	Mexico	54	55	109
	Philippines	133	1	134
	India	123	40	163
	Nigeria	69	103	173
	Weighted global average	*30*	*20*	*50*
Wheat	Denmark	12	11	22
	Egypt	9	14	23
	United Kingdom	13	11	24
	Germany	16	10	26
	France	14	16	30
	Pakistan	7	26	33
	Poland	25	23	48
	Mexico	24	24	49
	Czech Republic	23	33	56
	Italy	38	26	64
	Australia	69	0	69
	Romania	37	33	70
	China	33	44	75
	India	75	14	88
	Ukraine	36	55	91
	Russian Federation	53	39	92
	Turkey	59	37	97
	Canada	58	40	98
	Spain	38	63	102

	Argentina	0	126	126
	United States	42	93	135
	Uzbekistan	3	156	159
	Syrian Arab Republic	28	193	221
	Iran	82	140	222
	Kazakhstan	8	434	442
	Weighted global average	*39*	*55*	*93*
Cassava	Nigeria	44	0	44
	Brazil	95	10	105
	Thailand	94	12	106
	Congo, Dem. Rep. of	113	3	116
	Indonesia	80	39	119
	Ghana	85	47	131
	India	134	0	134
	Tanzania	135	0	135
	Mozambique	81	60	141
	Angola	128	15	143
	China	166	0	166
	Paraguay	134	35	169
	Uganda	173	5	178
	Benin	135	44	179
	Cameroon	120	71	191
	Colombia	110	82	192
	Cote d'Ivoire	207	0	207
	Guinea	237	0	237
	Madagascar	213	42	255
	Malawi	293	0	293
	Philippines	253	48	301
	Viet Nam	128	204	332
	Weighted global average	*128*	*22*	*150*
Potato	Spain	22	6	28
	Netherlands	18	14	32
	United Kingdom	16	17	33
	Germany	20	16	36
	France	18	18	36
	Japan	48	0	48
	Belgium-Lux.	24	25	49
	South Africa	24	26	51
	United States	24	28	52
	Turkey	22	31	53
	Pakistan	12	40	53
	Argentina	43	10	53
	Egypt	22	32	54
	Italy	31	31	62
	Canada	29	36	65
	Poland	41	52	93
	Colombia	86	7	93
	Lithuania	61	44	104

	India	99	12	111
	Brazil	96	20	115
	Iran	22	99	120
	Bangladesh	127	0	127
	Peru	128	0	128
	Romania	54	79	133
	China	74	62	135
	Malawi	135	6	141
	Belarus	73	70	142
	Russian Federation	78	72	149
	Ukraine	74	86	159
	Kazakhstan	0	300	300
	Weighted global average	*57*	*46*	*103*
Paddy rice	Egypt	7	20	27
	Korea	21	15	36
	Japan	43	2	45
	China	30	17	47
	United States	27	27	55
	Indonesia	58	16	74
	Bangladesh	74	1	75
	Viet Nam	73	3	76
	Brazil	60	32	92
	Myanmar	56	38	94
	Philippines	94	16	109
	Pakistan	45	67	113
	Thailand	88	37	126
	India	68	64	132
	Nepal	108	35	143
	Cambodia	111	74	185
	Nigeria	79	198	276
	Weighted global average	*47*	*35*	*82*
Barley	Russian federation	54	55	110
	Canada	31	31	61
	Germany	15	10	26
	France	12	15	27
	Spain	27	12	38
	Turkey	30	29	60
	Australia	46	72	119
	Ukraine	44	47	91
	United Kingdom	14	13	27
	United States	37	36	72
	Denmark	14	15	29
	China	41	32	73
	Czech republic	20	49	69
	Iran	50	121	171
	Poland	28	32	60
	Austria	26	10	36
	Belarus	47	44	91

	Bulgaria	31	40	70
	Ethiopia	148	7	155
	Finland	28	3	55
	India	101	7	108
	Ireland	13	7	20
	Italy	28	22	50
	Kazakhstan	1	284	285
	Lithuania	32	22	54
	Morocco	13	7	20
	Romania	31	51	82
	Sweden	18	17	35
	Syria	44	237	281
	Weighted global average	*34*	*38*	*72*
Sorghum	Egypt	12	11	23
	France	13	12	25
	Argentina	30	3	33
	China	39	21	60
	Australia	33	36	69
	United States	28	43	71
	Venezuela	76	0	76
	South Africa	44	39	82
	Mexico	35	50	85
	Ethiopia	123	0	123
	Brazil	97	26	123
	Cameroon	71	55	127
	Uganda	117	18	135
	Nigeria	159	0	159
	Ghana	154	21	175
	Yemen	0	180	180
	Tanzania	139	76	215
	Mali	182	59	241
	Chad	274	0	274
	Burkina Faso	233	43	277
	India	251	92	343
	Sudan	59	614	672
	Niger	781	294	1074
	Weighted global average	*103*	*79*	*182*
Rye	Sweden	15	13	28
	Denmark	16	13	29
	Germany	16	14	30
	France	17	21	38
	Austria	31	11	42
	Czech rep.	30	13	43
	Turkey	10	39	50
	Lithuania	46	28	74
	Poland	40	40	80
	United States	68	20	88
	China	62	27	89

	Spain	44	49	93
	Canada	46	48	94
	Ukraine	54	49	104
	Belarus	58	46	104
	Russian federation	61	53	114
	Weighted global average	*42*	*36*	*78*
Soybean	India	366	151	516
	Indonesia	137	177	313
	China	146	91	238
	Bolivia	65	137	202
	United States	100	95	194
	Canada	60	129	188
	Brazil	7	134	140
	Argentina	56	50	107
	Paraguay	69	37	106
	Italy	47	51	99
	Weighted global average	*78*	*95*	*173*
Rapeseed	India	240	553	793
	Bangladesh	624	0	624
	Pakistan	262	330	592
	Australia	202	241	443
	United States	142	279	421
	Canada	145	270	416
	China	173	223	395
	Poland	82	87	170
	Czech republic	84	67	152
	France	69	58	127
	Denmark	90	37	126
	United Kingdom	68	57	125
	Germany	73	46	119
	Weighted global average	*154*	*229*	*383*
Jatropha	Brazil	110	63	173
	Indonesia	127	75	202
	Nicaragua	83	129	212
	Guatemala	165	231	396
	India	396	770	1167
	Weighted global average	*165*	*231*	*396*

Appendix 12. The water footprint of bio-ethanol for two sugar and eight starch crops for the main producing countries (m^3/GJ)

Crop	Country	Water footprint in m^3 water per GJ ethanol		
		Green water footprint	Blue water footprint	Total water footprint
Sugar beet	Morocco	18	4	22
	Chile	14	11	25
	France	14	12	26
	Austria	24	3	22
	Ireland	18	17	34
	Denmark	23	11	34
	Netherlands	14	21	35
	Germany	20	17	36
	United Kingdom	16	21	37
	Japan	37	0	37
	Egypt	12	25	37
	Sweden	19	19	38
	Czech republic	29	14	43
	Greece	11	34	44
	Turkey	19	29	48
	Belgium-Lux.	24	25	49
	Italy	20	30	50
	Hungary	30	21	51
	United States	27	28	54
	Poland	26	34	61
	Slovakia	32	30	62
	Serbia	32	50	82
	Belarus	42	42	84
	China	62	36	97
	Romania	48	94	142
	Moldova	56	90	140
	Iran	17	130	147
	Ukraine	54	108	162
	Russian federation	30	144	174
	Weighted global average	*24*	*35*	*59*
Sugar cane	Peru	43	3	47
	Australia	38	32	70
	Egypt	5	66	72
	Colombia	19	59	79
	China	58	25	83
	Guatemala	42	41	84
	Mexico	31	56	87
	Argentina	4	90	94
	South Africa	35	63	98
	Brazil	57	41	99
	Philippines	62	38	100
	United States	33	71	104

	Indonesia	68	43	111
	India	31	87	118
	Thailand	64	55	118
	Pakistan	37	93	130
	Venezuela	68	66	135
	Viet Nam	93	50	143
	Bangladesh	106	44	150
	Cuba	141	84	225
	Weighted global average	*49*	*58*	*108*
Maize	Spain	18	23	41
	France	21	21	42
	Italy	22	22	43
	Germany	26	21	47
	Egypt	20	28	49
	Argentina	60	6	66
	Canada	33	40	74
	United States	41	37	78
	South Africa	93	0	93
	China	76	41	117
	Brazil	90	51	140
	Thailand	71	80	150
	Romania	71	104	175
	Indonesia	151	43	194
	Ukraine	72	132	204
	Mexico	117	121	238
	Philippines	191	1	292
	India	269	87	356
	Nigeria	151	226	377
	Weighted global average	*67*	*43*	*110*
Wheat	Denmark	26	24	50
	Egypt	21	32	53
	United Kingdom	30	24	53
	Germany	36	22	58
	France	32	36	69
	Pakistan	16	58	74
	Poland	57	51	108
	Mexico	55	55	110
	Czech Republic	53	75	128
	Italy	86	59	145
	Australia	157	0	157
	Romania	83	75	158
	China	75	94	169
	India	169	31	200
	Ukraine	81	124	205
	Russian Federation	120	88	209
	Turkey	134	85	219
	Canada	130	91	221
	Spain	87	144	230

	Argentina	0	285	285
	United States	95	211	306
	Uzbekistan	7	354	360
	Syrian Arab Republic	64	438	501
	Iran	186	316	502
	Kazakhstan	19	982	1001
	Weighted global average	*81*	*134*	*215*
Cassava	India	37	0	37
	Thailand	79	8	88
	China	78	10	89
	Indonesia	94	2	97
	Cameroon	67	33	100
	Paraguay	70	39	109
	Nigeria	111	0	111
	Benin	112	0	112
	Brazil	68	50	117
	Ghana	107	12	119
	Viet Nam	138	0	138
	Uganda	111	29	140
	Congo, Dem. Rep. of	144	4	148
	Tanzania	113	36	149
	Malawi	100	59	159
	Colombia	92	68	160
	Philippines	173	0	173
	Angola	197	0	197
	Madagascar	178	35	212
	Guinea	243	0	243
	Mozambique	211	40	250
	Cote d'Ivoire	107	170	276
	Weighted global average	*107*	*18*	*125*
Potato	Spain	22	6	28
	Netherlands	18	14	32
	United Kingdom	16	17	33
	Germany	20	16	35
	France	18	18	36
	Japan	48	0	48
	Belgium-Luxemburg	24	25	49
	South Africa	25	26	51
	United States	24	28	52
	Turkey	22	31	53
	Pakistan	43	10	53
	Argentina	12	40	53
	Egypt	22	32	54
	Italy	31	31	62
	Canada	30	36	65
	Poland	41	52	93
	Colombia	86	7	93
	Lithuania	60	44	104

	India	99	12	111
	Brazil	96	20	115
	Iran	21	99	120
	Bangladesh	127	0	127
	Peru	128	0	128
	Romania	54	79	133
	China	73	62	135
	Malawi	135	6	146
	Belarus	73	70	142
	Russian Federation	77	72	149
	Ukraine	74	85	159
	Kazakhstan	0	300	300
	Weighted global average	*56*	*46*	*103*
Paddy rice	Egypt	17	44	60
	Korea	46	33	79
	Japan	96	5	101
	China	67	38	105
	United States	61	61	122
	Indonesia	130	36	166
	Bangladesh	165	2	166
	Viet Nam	170	7	163
	Brazil	133	72	205
	Myanmar	125	84	209
	Philippines	209	35	244
	Pakistan	101	150	251
	Thailand	197	83	280
	India	151	142	293
	Nepal	240	77	318
	Cambodia	247	164	412
	Nigeria	175	440	615
	Weighted global average	*121*	*70*	*191*
Barley	Ireland	29	15	44
	Morocco	29	16	44
	Germany	34	23	58
	United Kingdom	30	30	60
	France	26	35	61
	Denmark	32	34	66
	Sweden	41	39	80
	Austria	159	23	82
	Spain	60	26	86
	Italy	64	49	113
	Lithuania	73	49	122
	Finland	62	63	125
	Turkey	68	66	134
	Poland	62	72	135
	Canada	70	69	138
	Czech republic	46	111	157
	Bulgaria	70	89	159

	United States	83	80	163
	China	93	73	165
	Romania	70	116	186
	Ukraine	99	106	205
	Belarus	106	99	206
	India	229	14	243
	Russian federation	123	125	248
	Australia	105	163	268
	Ethiopia	334	15	349
	Iran	113	273	386
	Syria	100	534	634
	Kazakhstan	3	640	643
	Weighted global average	*70*	*89*	*159*
Sorghum	Egypt	28	25	53
	France	30	27	57
	Argentina	70	8	77
	China	89	49	138
	Australia	76	83	159
	United States	64	100	164
	Venezuela	176	0	176
	South Africa	101	89	190
	Mexico	80	116	195
	Ethiopia	283	0	283
	Brazil	223	60	283
	Cameroon	165	128	293
	Uganda	269	42	312
	Nigeria	367	0	367
	Ghana	355	48	403
	Yemen	0	414	414
	Tanzania	321	176	497
	Mali	420	136	556
	Chad	632	0	632
	Burkina Faso	538	100	638
	India	579	213	792
	Sudan	135	1416	1551
	Niger	1800	677	2477
	Weighted global average	*238*	*182*	*419*
Rye	Sweden	32	28	60
	Denmark	34	30	64
	Germany	35	31	66
	France	37	46	83
	Austria	69	23	92
	Czech rep.	65	28	94
	Turkey	23	86	109
	Lithuania	100	62	162
	Poland	87	87	174
	United States	149	44	193
	China	136	58	194

Spain	96	108	204
Canada	101	104	206
Ukraine	118	108	227
Belarus	127	101	228
Russian federation	133	116	249
Weighted global average	*92*	*79*	*171*

Appendix 13. The water footprint of biodiesel from soybean, rapeseed and jatropha for the main producing countries (m^3/GJ)

		Water footprint in m^3 water per GJ biodiesel		
Crop	Country	Green water footprint	Blue water footprint	Total water footprint
Rapeseed	Germany	78	49	127
	United Kingdom	73	61	134
	Denmark	96	39	135
	France	74	62	136
	Czech republic	90	72	162
	Poland	88	93	182
	China	185	238	422
	Canada	155	288	444
	United States	152	298	450
	Australia	216	257	473
	Pakistan	280	353	633
	Bangladesh	667	0	667
	India	256	591	847
	Weighted global average	165	245	409
Soybean	Italy	833	117	225
	Paraguay	311	85	242
	Argentina	332	115	244
	Brazil	148	305	320
	Canada	227	293	428
	United States	136	216	443
	Bolivia	16	312	460
	China	128	208	541
	Indonesia	157	403	714
	India	108	343	1176
	Weighted global average	177	217	394
Jatropha	Brazil	160	91	251
	Indonesia	184	109	293
	Nicaragua	120	187	307
	Guatemala	156	174	329
	India	575	1116	1691
	Weighted global average	239	335	574

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