GLOBAL WATER FOOTPRINT OF INDUSTRIAL HEMP TEXTILE

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GLOBAL WATER FOOTPRINT OF INDUSTRIAL HEMP TEXTILE - SUMMARY

Since time immemorial there is no product group that is closer to our skin than clothes. Nowadays 36% of the worldwide clothes are produced from cotton lint. The disadvantage to the use of cotton for the production of textile is cotton's adverse on natural water flows and water quality on water basins.

Using other natural crops for the production of textiles may decrease the impact on the environment given the lower water requirements of many other fibre crops. One of these is hemp, which was already used in the distant past. The water footprint (WF) of industrial hemp, based on earlier studies, is less than one third of the WF of cotton (10,000 l/kg vs. 2,719 l/kg).

For a more detailed understanding of the WF of industrial hemp a deeper investigation was needed. Therefore the goal of this study is to determine the global average WF of industrial hemp textiles. The global average WF is divided in the green, blue and grey WF. Based on the top-ten industrial hemp producing countries in the world the global average WF is calculated.

- The global average green WF refers to the consumption of rainwater. For this study this is determined by implementing industrial hemp in AquaCrop. This model is able to simulate the yield and evapotranspiration of crops under various conditions. The global average green WF of industrial hemp in the growing stage is calculated at 1,922.1 m^3/ton.

- The global average blue WF depends on the amount of irrigation. Industrial hemp, however, is generally not irrigated, so the global average blue WF in the growing stage is zero.
- The global average grey WF depends on the use of fertilizers. With an application rate of 150 kg/ha of N, nitrogen is generally the dominant fertilizer component. This results in a global average grey WF of industrial hemp of 644.6 m^3/ton.
- The total global average WF of industrial hemp in the growing stage is the sum of the green, blue and grey WF's; the global average WF is 2,566.7 m^3/ton.

The WF of industrial hemp based products depends on product and value fractions and the required processing steps from crop to product of the industrial hemp. The textile from industrial hemp comes from the bast fibre of the stalk of the crop. With the equation to calculate the WF of industrial hemp based products the WF of industrial hemp textile are determined; WF of industrial hemp textiles is 2,819.9 m^3/ton.

It can be concluded that earlier studies on the WF of industrial hemp textile had already drawn the right conclusion. The WF of cotton textile is more than three times larger than the WF of industrial hemp textile. Besides, the production areas of cotton are often in water scarce regions in the world. Industrial hemp is mainly grown in parts of the world where a little or no water scarcity is, so production of industrial hemp is less impactful on water resources.

WATER FOOTPRINT VAN INDUSTRIËLE HENNEP TEXTIEL - SAMENVATTING

Sinds jaar en dag is er geen product groep te bedenken die dichter aan onze lichamen is dan kleding. Tegenwoordig is 36% van de wereldwijde hoeveelheid aan kleding geproduceerd van katoen. Het nadeel aan het gebruik van katoen voor de productie van textiel is zijn de negatieve effectie van katoen voor de natuurlijke water stromen en de water kwaliteit van water basins.

Het gebruiken van andere natuurlijke gewassen voor de productie van textiel zal de impact op het milieu verminderen door de lagere water vereisten van deze gewassen. Een voorbeeld hiervan is hennep, hennep werd al gebruikt voor textiel in het verre verleden. De water footprint (WF) van industriële hennep, gebaseerd op eerder onderzoek, is minder dan een derde van de WF van katoen (10.000 l/kg voor katoen tegenover 2.719 l/kg voor hennep).

Voor een meer gedetailleerde WF van industriële hennep is een diepgravender onderzoek nodig. Het doel van dit onderzoek is daarom ook om het globale gemiddelde WF van industriële hennep textiel te bepalen. De WF is opgedeeld in de groene, blauwe en grijze WF. Op basis van de top tien industriële hennep producerende landen in de wereld het wereldwijde gemiddelde van de WF is berekend.

- De groene WF refereert aan de consumptie van neerslag. In dit onderzoek is dit bepaald door middel van het simuleren van het groeiproces van industriële hennep in AquaCrop. Dit is een model dat in staat is om de opbrengst en de verdamping van gewassen onder variërende omstandigheden te simuleren. Het globale gemiddelde groene WF in de groeifase is 1922,1 m^3/ton.
- De blauwe WF van industriële hennep is afhankelijk van de hoeveelheid irrigatie die wordt toegepast tijdens het groeiproces van het gewas. Echter, industriële hennep wordt normaal gesproken niet geïrrigeert, daarom is de globale gemiddelde blauwe WF in de groeifase nul.

- De globale gemiddelde grijze WF is afhankelijk van het gebruik en toepassen meststoffen op de gewassen. Een dosing van 150 kg/ha van N (stikstof) is normaal gesproken de dominante meststof component voor industriële hennep. Dit resulteerd in een globaal gemiddelde grijze WF van 644,6 m^3/ton.
- De totale globale gemiddelde WF van industriële hennep in de groeifase van het gewas is de som van de groene, blauwe en grijze WF die hierboven genoemd zijn; de globale gemiddelde WF voor industriële hennep is 2566,7 m^3/ton.

De WF van producten die gebaseerd zijn op industriële hennep zijn afhankelijk van de product fractie, waarde fractie en de benodigde proces stappen van gewas tot textiel van industrieel hennep. De textiel van industrieel hennep is afkomstig uit de vezel van de stengel van de plant. Met de formule om de WF van industriële hennep gebaseerde producten te berekenen is de wereldwijde gemiddelde WF van industriële hennep textiel bepaald; de WF van industriële hennep textiel is 2819,9 m^3/ton.

Op basis van de bovenstaande resultaten van het onderzoek naar de wereldwijde gemiddelde WF van industriële hennep en het hierop gebaseerde textiel dat eerdere onderzoeken de juiste conclusie hebben getrokken. De globale gemiddelde WF van katoen textiel is meer dan drie keer zo groot dan de wereldwijde gemiddelde WF van industriële hennep textiel. Daarnaast, de locaties waar katoen verbouwd worden bevinden zich voor het grootste deel in gebieden waar water schaarste heerst. Industriële hennep daarentegen wordt voornamelijk verbouwd in delen van de wereld waar geen of weinig water schaarste voor komt. De productie van industriële hennep is dus minder belastend voor het milieu dan de productie van katoen.

CONTENTS

1 INTRODUCTION

It is hard to find a product group that is closer to our skin than clothing (Kooistra & Termorshuizen, 2006). Clothing is generally made of cloth. There are many different types of cloth, the distinction can be made between natural materials and synthetic fibres. One of the oldest materials for producing clothing is cotton. In Mexico scientists found bits of cotton bolls and pieces of cotton cloth that proved to be at least 7,000 years old (Cotton counts, 2014). Nowadays cotton is still part of our daily lifes (Cotton counts, 2014). Up until the 18th century the share of the natural fibres used in textiles was 78% wool, 18% flax and 4% cotton. Due to technical innovations however this has now changed and today cotton takes up 36% of textile production, while 45% is taken up by synthetics and the rest accounted for by other fibres (Barlocher, et al., 1999).

1.1 The research problem

As mentioned 36% of the textile production is taken up by cotton (Hoekstra, 2013). Cotton is a very water intensive product (Hoekstra, 2013). So for the total world production of cotton clothes a very large amount of water is necessary. The production and consumption of a cotton product (mostly clothing) is connected to a chain of impacts on the water resources, environment, health and economy of the countries where it is grown and processed. If there is one single crop to be elected for its most disastrous effects on natural water flows and water quality on water basins, cotton has a good chance of winning (Hoekstra, 2013). The blame is of course not on cotton, but on the people that have decided to grow it at too large a scale in unsuitable regions.

One of the most notorious example is the distressing situation of the Aral Sea. The Aral Sea region in Central Asia is such a region that is famous for its conflict between sustaining irrigated agriculture and preserving the environment (Cai, et al., 2003). In this region are mainly cotton and rice cultivated. The effects of the increasing agricultural activities in cultivating cotton are shown in Figure 1. This graph shows the development of the water surface of the Aral Sea by the increase of the irrigated area in the Aral Sea region.

This observation shows that the water surface of the Aral Sea is more than halved in about the last 50 years. What this in reality means for the Aral Sea area is shown in Figure 2, here the development of the coastline of the Aral Sea from 1960 up to 2009 is shown in six steps.

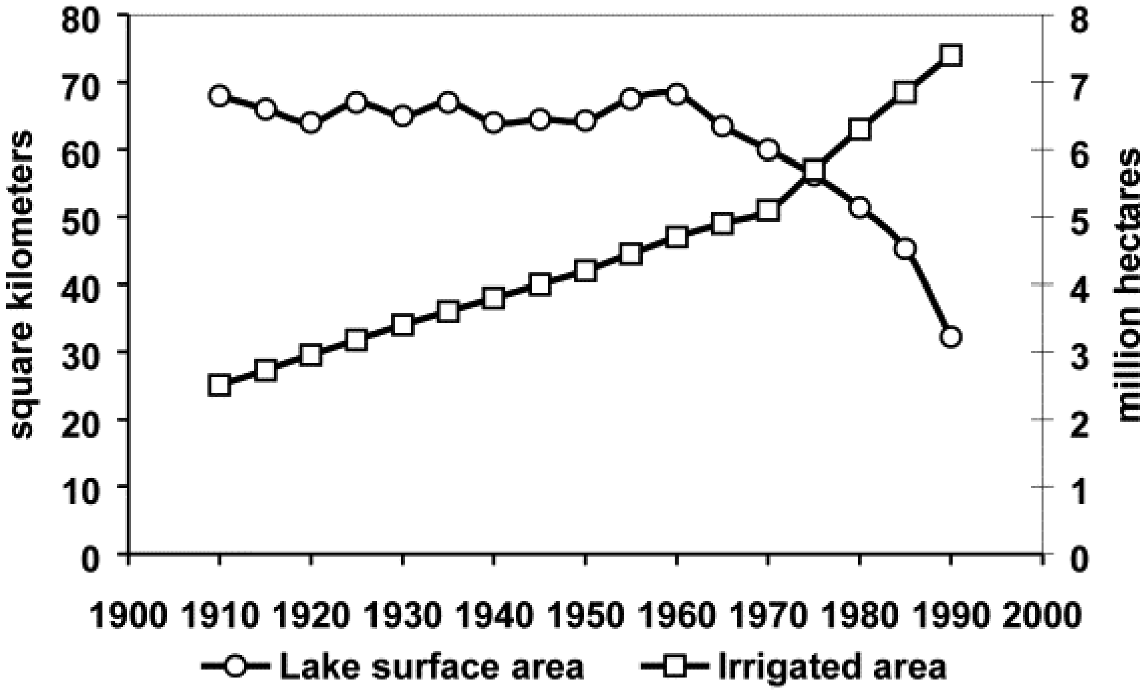

FIGURE 1. DEVELOPMENT OF THE WATER SURFACE OF THE ARAL SEA BY THE INCREASE OF THE IRRIGATED AREA IN THE ARAL SEA REGION OVER TIME (CAI, ET AL., 2003)

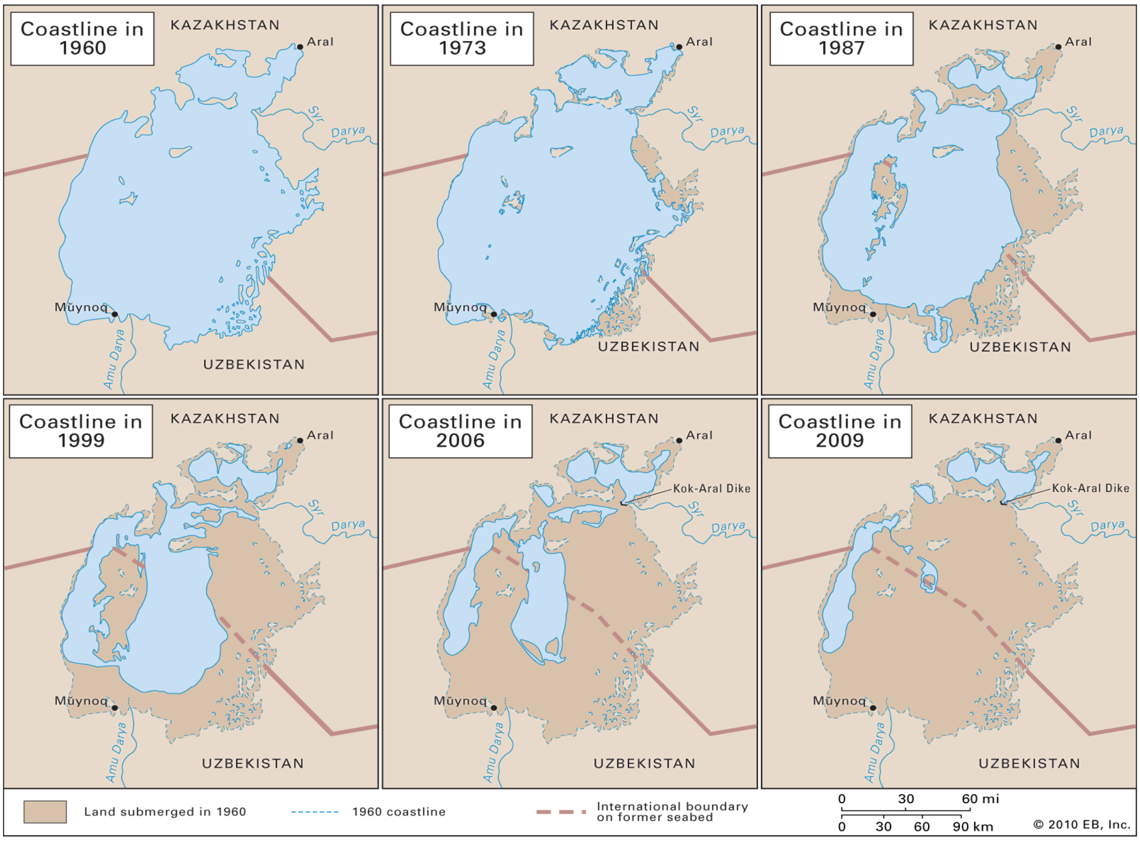

FIGURE 2. IMPACT OF WATER ABSTRACTION FOR THE ARAL SEA AREA (MAPPERY, 2011)

So researchers are looking for alternative raw materials for the production of textiles. One of these is the industrial hemp. The conditions to harvest hemp results in less water use in comparison with cotton. For cotton the water footprint is known. But what is exactly the water footprint of hemp? What amount of water can be saved by replacing cotton by hemp? To answer this questions the production chain from hemp to textile need to be analysed to determine the water footprint of hemp for the production of textiles.

1.2 Goal and objectives

The purpose of the study is to determine the water footprint for the production of textiles from industrial hemp. If this is known and supported by scientific research the proponents of hemp-textiles haves a strong argument in their attempts to promote the production of textiles from industrial hemp instead of cotton and other raw materials.

To get insight in the water footprint of textiles from industrial hemp and the comparison with cotton the following objectives, to reach the main goals of this study, are formulated:

- Understanding the total production chain for the production of textiles from industrial hemp
- Calculating the water footprint of textiles from industrial hemp based on its yield with the AquaCrop model
- Determining the water footprint of all the processing steps of the textile production from industrial hemp
- Calculating the water footprint for all the possible different fractions of the hemp plant
- Making the comparison between industrial hemp and cotton as raw materials for textiles and consider the product with the lowest water footprint as the durable responsible kind of textile for the future.

2 THEORETICAL FRAMEWORK

Freshwater resources are becoming scarcer due to different factors. The world population is growing, deterioration of water quality, climate change, etc. Professor Hoekstra (2013) stated: ‘freshwater is a renewable but finite resource’. In this sense renewable means that the resource is naturally replenished or formed in the course of time. Freshwater stocks on land, although they get depleted by evaporation and drainage to the oceans, will always be replenished by precipitation. Although freshwater is renewable, it is also a finite resource. In this sense finite means that water availability is limited. Over a certain period, precipitation is always limited to a certain amount (Hoekstra, 2013). Because freshwater is becoming scarcer, is renewable but also limited the attention for water saving in all kinds of measures are developed to decrease the water demand of the world. Some of these are effective, other seems to be effective but in reality they are really doesn’t matter. For example a campaign to decrease the active use of water in a household. People think that they can save the world by showering one or a few minutes less and stop spilling any water. In reality this doesn’t make sense because the water use in the households is only one percent of the total water footprint of a household (Blok, 2015).

So to reduce the global water footprint other elements that have a large impact on the water footprint needs to change. Large consumers of the global freshwater are for example meat, spices, coffee beans, and cotton (Volkskrant, 2014). Hardly nobody in the world doesn’t use textiles, so reducing the demand for the textile production will significantly decrease the world water demand and thereby the global water footprint.

Cotton is the most important natural fibre used in textile industries worldwide, contributing 36 per cent of apparel fibres in 2008 (Hoekstra, 2013). The global average water footprint of cotton fabric is approximately 10,000 litre/kg (Hoekstra, 2013). Compared with other raw materials a textiles there possibilities to decrease the water footprint for the global textile use. Table 1 shows the global average water footprints of different raw materials for textiles. Based hereon we can concluded that cotton is one of the largest water users in textile production. By replacing cotton with hemp will result in a significant decrease of the demand of water and also a significant decrease of the water footprint of textiles because the water footprint of hemp is about 2,700 litre/kg (Hoekstra, 2013).

TABLE 1. THE GLOBAL AVERAGE WATER FOOTPRINT OF DIFFERENT RAW MATERIALS OF TEXTILE (HOEKSTRA, 2013)

Product	**Global average water footprint (litre/kg)**			
	Green	**Blue**	**Grey**	**Total**
Abaca fibre	21,529	273	851	22,653
Cotton lint	5,163	2,955	996	9,114
Sisal fibre	6,791	787	246	7,824
Agave fibre	6,434	9	106	6,549
Ramie fibre	3,712	201	595	4,508
Flax fibre	2,866	481	436	3,783
Hemp fibre	2,026	0	693	2,719
Jute fibre	2,356	33	217	2,606

Hemp fibre is in Table 1 the fibre with almost the lowest water footprint. In early days it was common to use hemp for the production of a lot of different products. For example in the shipping: "*In the 16th Century, Henry VIII encouraged farmers to plant the crop extensively to provide materials for the British Naval fleet. A steady supply of hemp was needed for the construction of battleships and their components. Riggings, pendants, pennants, sails, and oakum were all made from hemp fibre and oil. Hemp paper was used for maps, logs, and even for the Bibles that sailors may have brought on board"* (Hemp, 2015) But in the last century hemp was seen as a threat. Hemp was associated with marijuana by the competing industries (Hemp, 2015). This finally results in the prohibition of the production of hemp in many countries.

2.1 About (industrial) hemp

But why do we not use the hemp plant? The stalk of the hemp plant is one of the strongest natural fibres in the world. And if we compare hemp with cotton it can be concluded that hemp is softer than cotton, warmer than cotton, more water absorbent than cotton, many times more durable than cotton (Stexfibers, 2014). The production of hemp require much less water than the production of cotton. The cotton production involves 25% of world's pesticide use while the production of hemp does not require pesticides to grow (Martino, 2013). So after all these benefits you maybe think 'why don't we use this stuff all the time...for everything?'. The simplest reason is that hemp is related to drugs and therefore it is often prohibited.

Solution for this problem is the use of industrial hemp. Industrial hemp and marijuana are different varieties of the same species, *Cannabis sativa* L. They only significantly differ in their content of the psychoactive ingredient delta-9-tetrahydrocannabinol (THC, the ingredient that makes you high). Industrial hemp contains less than 1% THC while marijuana contains about 3%-15% or more THC (Fortenbery & Bennett, 2004); (Hempethics, 2015).

Industrial hemp is an annual plant which grows every year from seed. It has a rigid, herbaceous stalk which can range anywhere from 3 to 16 feet (0.9 to 4.8 meters) in height (Kraenzel, et al., 1998). The female flowers and seeds are indeterminate, meaning that there are both ripe and immature seeds on the same plants at the time of grain harvest (Hemp Technologies, 2015).

FIGURE 3. THE WELL-KNOWN 7 LEAVES OF THE HEMP PLANT (MARTINO J. , 2013)

The plant consists of several parts. The hemp is well-known of its 7 leaves as shown in Figure 3. But the plant also consists of the stalk, roots, flowers, and seeds. The stem/stalk has an outer bark that contains the long, tough bast fibres. They are similar in length to soft wood fibres and are very low in lignin content. Hemp rope, textiles and clothing is made from these fibres. The stalk contains the 'hurds' or 'shives' (short fibres), similar to hard wood fibres and these are used for building, particleboard and pet bedding, as well as plastics (Hemp Technologies, 2015). So from only the stalk the hemp plant has different possibilities. In

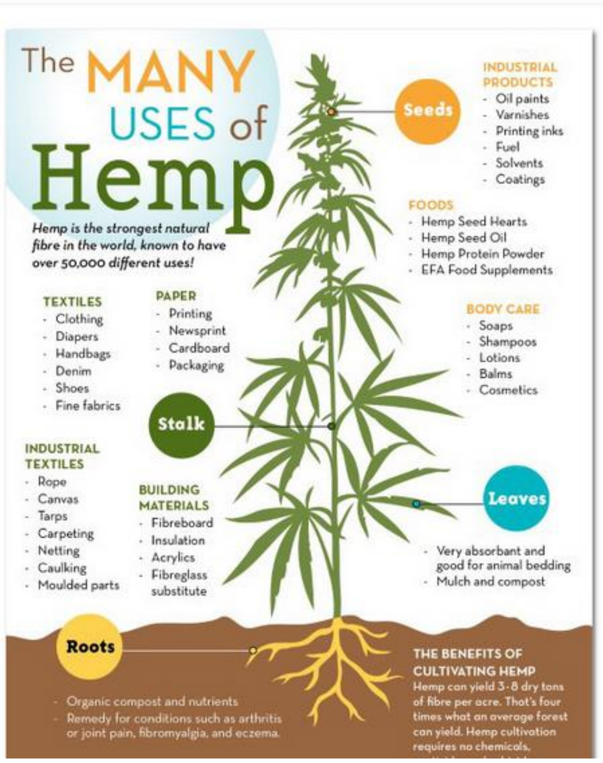

FIGURE 4. THE DIFFERENT ELEMENTS OF THE HEMP PLANT AND A FEW DIFFERENT USES OF HEMP (CANADA HEMP FOODS, 2015)

total there are an estimated 25,000 different hemp related products (Kraenzel, et al., 1998). An overview of the hemp plant and the few of the hemp related products are shown in Figure 4. Canada hemp foods Ltd. summarises the parts of the plant as follows (Canada Hemp Foods, 2015):

- Flower: powerful medicinal and spiritual properties
- Seed: full of protein, amino acids, and the essential fatty acids required to sustain human life
- Stalk: source of on the world's strongest natural industrial fibres
- Roots & leaves: feed the soil with valuable nutrients – a farmer can grow multiple crops of hemp per season in the same field for 10 years in a row without seeing a decrease in soil nutrients

The production of industrial hemp has great potential. The last decade's low narcotic varieties have been developed (industrial hemp) allowing cultivation in Europe once again, although hemp remains an illegal crop in the United States of America. The total world hemp fibre production in 2003 was approximately 77,450 tons. The represents only 0.15% of world's fibre production (Cherrett, et al., 2005). In comparison with cotton, this is a very small share of the world's fibre production there the share of cotton was 36% (and with that the word's most important source of fibres) (Hoekstra, 2013).

This great potential of industrial hemp is not only related to the share in the market of fibres. The hemp crop can be used for a lot of purposes. Both, the stalk and the seed of the industrial hemp are very useful. Figure 4 shows the uses of industrial hemp crop: seeds, stalk, leaves and roots. Hemp is a multi-use annual crop cultivated for fibre, animal feed and seed (Cherrett, et al., 2005). Hemp textile and hemp clothes are currently exported around the world in small quantities, but if this were to change it would need to overcome a series of technical constraints, involving the entire sequence of production and utilisation. At present, the traditional processing of hemp is stall at the same technological level it was at fifty years ago and consequently it is only viable in countries where labour costs are low (Cherrett, et al., 2005).

Nevertheless, producing hemp instead of cotton could be valuable development of a sustainable environment. Current studies already showed the much lower impact of hemp than cotton on nature with regard to water use. Table 1 shows a much lower water footprint in which is included the water use for cultivation and production and also the use of pesticides.

As mentioned there are approximately 25,000 hemp (Kraenzel, et al., 1998) related products. All these products can be separated in the following general submarkets (see Figure 5):

- Agriculture
- Automotive
- Construction materials
- Cosmetics
- Food/Nutrition/Beverages
- Furniture
- Paper
- Recycling
- Textiles

With such a wide variety and large numbers of uses, there is a great amount and rather diverse group of competitive commodities, raw materials and products. Cotton, lumber, and fossil fuels are some of the biggest and more powerful of these competitors (Kraenzel, et al., 1998).

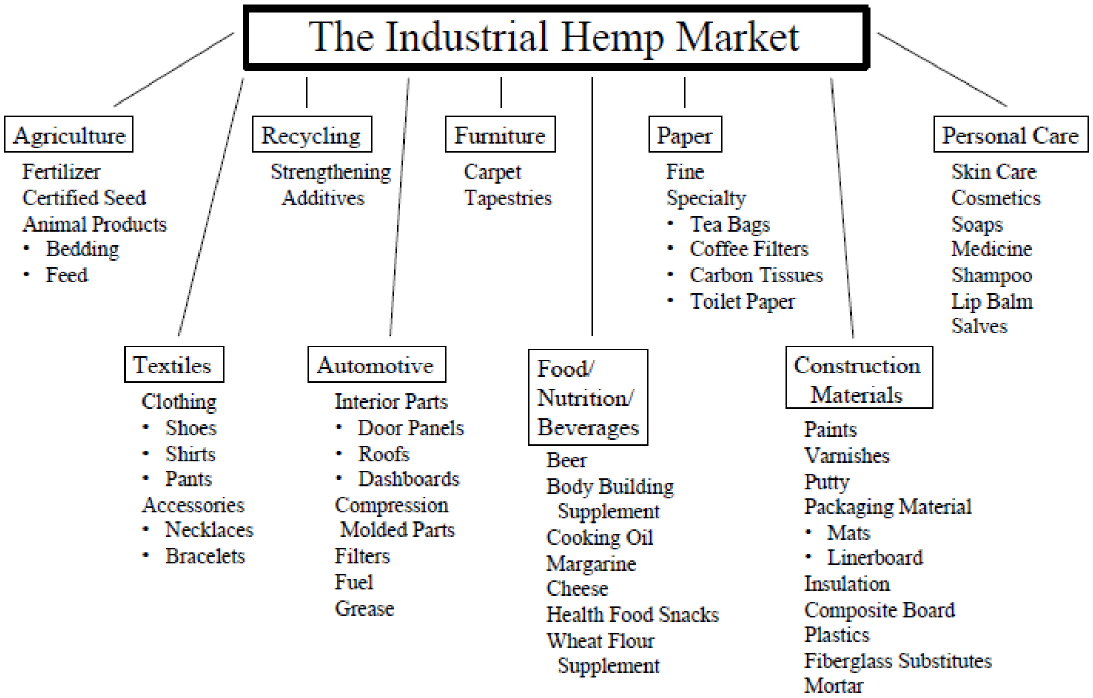

FIGURE 5. THE SUBMARKETS OF THE USES OF HEMP ((KRAENZEL, ET AL., 1998)

2.2 Characteristics of industrial hemp

Industrial hemp is currently legally produced in 22 countries (Kraenzel, et al., 1998). But beside the possibility by law to produce a product also the circumstances need to be suitable for growing the industrial hemp. In the following parts there will be discussed under which circumstances the hemp plant can be produced and also where the hemp production takes place.

The circumstances for growing hemp are also known as the agronomics. The agronomics of industrial hemp are divided into climate, soils, seeding and harvesting.

2.2.1 Climate

Industrial hemp can be grown almost anywhere but optimum industrial hemp growth occurs in a mild humid temperature climate. Four months free of killing frost are needed in order to produce the best fibre and 5 ½ months for seed production. Ideal temperatures for hemp growth range between 60 and 80 degrees Fahrenheit (16 – 27 degrees Celsius). When the average daily temperature reaches 61 degrees Fahrenheit (16 degrees Celsius) or higher, the plant enters into rapid growth stage, during which it grows 4 to 6 cm per day (Kraenzel, et al., 1998). However, it can endure both higher and lower temperatures, the seedlings and the mature plants can endure until -5 degrees Celsius (British Columbia Ministry of Argiculture and Food, 1999).

Especially the first six weeks, during germination and until the plant has become well rooted and established (Kraenzel, et al., 1998), the industrial hemp needs plenty of rainfall (British Columbia Ministry of Argiculture and Food, 1999). After the first period the plant can endure drier conditions. The ideal total rainfall for hemp ranges between 25 and 30 inches (635 – 760 mm) annually (Kraenzel, et al., 1998). Early plantings produce more mass for fibre production as it is a short day plant, maturing quicker as the days shorten in the summer and fall, so early growth is important. For seed production, later plantings may reduce stem length and mass (British Columbia Ministry of Argiculture and Food, 1999).

2.2.2 Soils

Industrial hemp plants prefers well drained loam soils. A soils pH over 6.0 is recommended, 7.0 – 7.5 preferred (British Columbia Ministry of Argiculture and Food, 1999). The loam soil with a loose texture and containing a plentiful supply of decaying vegetable matter of an alluvial deposit alkaline and not acid in reaction is ideal for industrial hemp production (Kraenzel, et al., 1998), industrial hemp is very sensitive to soil compaction (British Columbia Ministry of Argiculture and Food, 1999).

2.2.3 Seeding and harvesting

Industrial hemp is a dioeciously plant. This means that the male plant bears male flowers with pollen and the female plant contains the ovary, from which the fruit later develops. This simply means that there are two separate hemp plants. The male, which is the best fibre producer, and the female that is the seed producer (Kraenzel, et al., 1998).

The harvesting times and methods are different for fibre and seed production. In fibre production, harvesting occurs as soon as the last pollen is shed. Usually harvesting for fibre takes place 70 to 90 days after seeding. Harvesting for seed started when 60% of the seed in ripened. This occurs usually 4 to 6 weeks later than the when the hemp is harvested for the hemp fibre (Kraenzel, et al., 1998).

3 METHOD AND DATA

To determine the water footprint of textiles from industrial hemp it is necessary to describe the method that will be used. Therefore briefly the concept of the water footprint need to be explained.

The water footprint is an indicator of freshwater use that looks not only at direct water use of a consumer or producer, but also at the indirect water use (Hoekstra, et al., 2011). The water footprint of a product is the volume of freshwater used to produce the product, measured over the full supply chain (Hoekstra, et al., 2011). The water footprint of a product (alternatively known as "virtual water content") expressed in water volume per unit of product (usually m^3/ton) is the sum of the water footprints of the process steps taken to produce the product (Mekonnen & Hoekstra, 2011). Each water footprint consists of three parts: the green, blue and grey water footprint.

- The green water footprint refers to consumption of green water resources (rainwater insofar it does not become run-off or deep percolation)
- The blue water footprint refers to consumption of blue water resources (surface and groundwater) along the supply chain of a product
- The grey water footprint refers to pollution and is defined as the volume of freshwater that is required to assimilate the load of pollutants given natural background concentration and existing ambient water quality standards (Hoekstra, et al., 2011).

Water footprint accounts give spatiotemporally explicit information regarding how water is appropriated for various human purposes (Hoekstra, et al., 2011).

To study wherein the water footprint of textiles from industrial hemp is investigated will be an explanatory research. The goal is to get insights in the relevant variables, in this case the water use (green, blue and grey water footprint) of industrial hemp. But also some parts of the research consist of an exploratory study. The market, production process, etc. needs to be described.

Therefore will be followed a mixed research design, which means a combination of a qualitative and a quantitative research design. For example the description of the production process of industrial hemp is qualitative research. But the calculation of the total water footprint of textiles from industrial hemp is quantitative.

3.1 Global Water footprint of industrial hemp

3.1.1 Data input of the AquaCrop model

For the calculation of the water footprint of the complete plant of industrial hemp a model will be used. The model that will be used is AquaCrop. AquaCrop is the FAO (Food and Agriculture Organization of the United Nations (FAO, 2015)) crop-model to simulate yield response to water of several herbaceous crops. It is designed to balance simplicity, accuracy and robustness and is particularly suited to address conditions where water is a key limited factor in crop production (FAO, 2015).

Hemp producing countries and regions

By implementing a range of locations where industrial hemp is produced the water footprint for these locations will be determined. Based on these value the global water footprint of hemp will be calculated. For using AquaCrop a few elements needs to be investigated before getting the water footprint of producing hemp. Needed input information are climate, crop, crop management and soils.

To determine the inputs for the climate first the countries where industrial hemp is produced are determined. The 10 largest producers of the world are shown in Table 2, herein is the production amount shown as the average of the last 25 years that are available (the period 1989 – 2013). The choice for this period is based on Figure 6 which shows the total global industrial hemp production of the period 1961 – 2013. From this graph can be concluded that the worldwide industrial hemp production have since 1989 more or less an amount of the same order of magnitude. The total global production is approximately 69,000 tons. While China is the largest worldwide producer. This country produces 37.3% of the total global production: 12,196 tons (FAOSTAT, 2015).

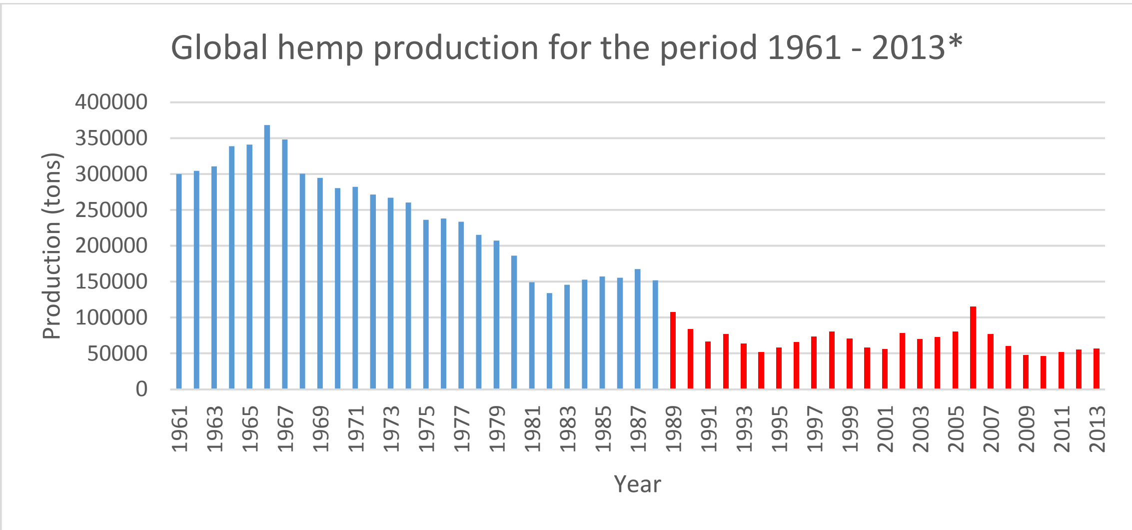

FIGURE 6. GLOBAL HEMP PRODUCTION IN THE PERIOD 1961 - 2013. IN RED THE PERIOD 1989 – 2013. *SOURCE: FAOSTAT (2015)

The more specific locations in the hemp producing countries is displayed in Table 3. The missing information can be found in researches about hemp production on several locations in the different top-ten hemp producing countries. The information of the locations of hemp productions is also available in crop-maps. Crop-maps are maps of the globe which shows what kind of crops are grown on what location. Ramankutty (2013) gathered and developed some databases to improve the understanding of human land use activities at continental to global scale. Also for 175 different crops he developed crop-maps, for the determination of the more specific region within the top fifteen countries the dataset of hemp can be used (Ramankutty, 2013). The data is implemented in ArcGIS ASCII data files which can be read by use of ArcGIS or other GIS tools. But for the hemp production the crop maps are not very precise, so there were not useable for determining the regions of hemp production in the top-ten hemp producing countries. Figure 7 shows a print screen of the available worldwide crop map of hemp.

TABLE 2. THE TOP-TEN HEMP PRODUCING COUNTRIES IN THE WORLD (PERIOD 1989-2013)

Countries	**Average production (ton/yr)**	**% contribution to global production**	**Yield (ton/ha)**
China	25,687.4	37.3%	2.01
Korea	12,195.6	17.7%	0.67
Romania	5,927.0	8.6%	2.30
USSR	5,060.0	7.3%	0.40
Netherlands	4,254.5	6.2%	7.50
Chile	4,171.7	6.1%	0.95
Spain	4,003.2	5.8%	3.66
Turkey	1,609.9	2.3%	1.12
Austria	1,223.0	1.8%	6.25
Ukraine	1,191.1	1,7%	0,53
Others	2,881.6	5,2%	-
World	68,911.3	100%	-

Source: FAOSTAT (2015)

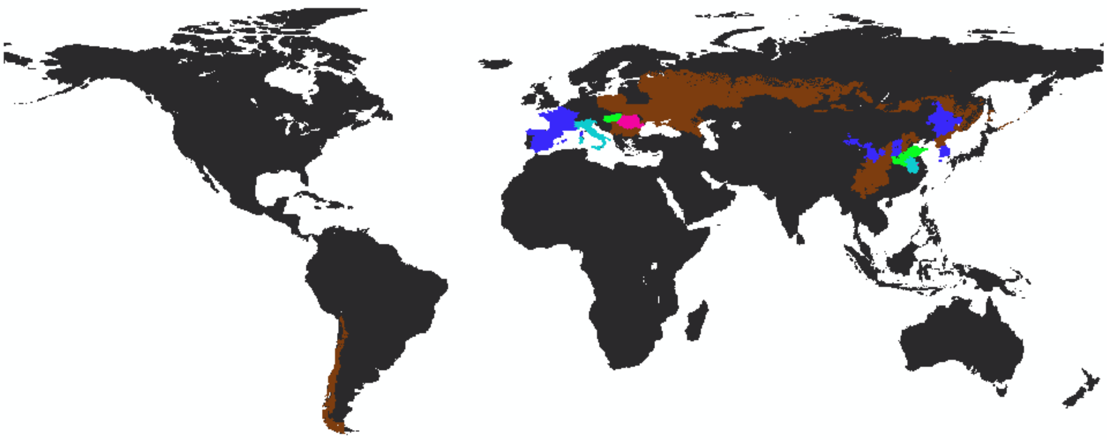

FIGURE 7. AVAILABLE INFORMATION FROM THE CROP MAP OF INDUSTRIAL HEMP. DATA FROM RAMANKUTTY (2013)

So the regions of hemp production are based upon a literature review. The results of this investigation is showed in Table 3. The soil type that is shown in Table 3 is based on the worldwide map of soils of the University of Tokyo (Koirala, 2015).

TABLE 3. THE MAJOR HEMP PRODUCING REGION IN THE TOP-TEN HEMP PRODUCING COUNTRIES AND CORRESPONDING SOIL TYPE

Countries	Major hemp producing regions	Soil type*
China	Yunnan Province (Cannabis Culture, 2009)	Clay
Korea	Boseong and Andong regions (Clarke, 2006)	Loam
Romania	West Romania (Holler, 2000)	Sandy Loam
USSR	Central South Russia (Hempworld, 2003)	Silt Loam
Netherlands	Groningen Province (Ronde, 2013)	Sandy loam
Chile	Whole country along the banks of rivers and lakes (Forster, 2015)	Clay Loam
Spain	East Spain (Miranda, 2015)	Loam
Turkey	Ankara region (Dewey, 2015)	Loam
Austria	Hanftal (Osterreichischer Hanf Verband, 2015)	Sandy Loam
Ukraine	Glukhov region (Hemp Farming the Latvia, 2015)	Silt Loam

*Source: University of Tokyo (Koirala, 2015)

Implementation of industrial hemp in the AquaCrop model

The crop wherefore the simulation in AquaCrop need to be done is industrial hemp. This specific crop is not implemented in the program yet. To implement the industrial hemp in AquaCrop, crop specific characteristics are needed. Than need to be investigated which of the crops that are implemented has some similarities with industrial hemp. The specifications of this specific crop can be changed to use the crop industrial hemp in the AquaCrop model. The characteristics that are needed are the crop type, planting method, cropping period and the length of the growing cycle. Part of this information is available in the Factsheet Industrial Hemp (British Columbia Ministry of Argiculture and Food, 1999). Also the time it takes until the hemp plant is mature, and ready to harvest is available in the Factsheet Industrial Hemp (British Columbia Ministry of Argiculture and Food, 1999).

In AquaCrop several crops are implemented. But hemp is not one of them. It takes a lot of time to implement new crops into the model, therefore a lot of knowledge, data and effort is needed. Also the new crop in the model need to be validated. Other possibility of implementing another crop in AquaCrop is using an existing crop, that have similarities with the crop that will be implemented and changing the important parameters of the crop like canopy (or LAI: Leaf Area Index) that are specific for industrial hemp.

Climate data

Based on these locations the climate data can be gathered. The climate data is based on the data that is available in CLIMWAT (FAO, 2013). CLIMWAT is a climatic database for a range of climatological stations worldwide. It offers observed agroclimatic data of over 5,000 stations worldwide (FAO, 2013). Available data is: minimum, average and maximum temperature, humidity, wind speed, sunshine hours, solar radiation, (effective) rainfall and evapotranspiration

(FAO, 2013). As input for the model of industrial hemp in AquaCrop the maximum and minimum temperature (in °C), the rainfall (in mm) and the evapotranspiration (in mm) are needed. From these are the monthly averages are available. These monthly averages are implemented in the AquaCrop model for all the ten different locations of industrial hemp production.

Canopy
Important is to know what the initial canopy of the hemp plant is. This is one of the conservative parameters of the plant and is the related to the percentage of the land cover of the plant after a few days after sowing. Besides the initial canopy also the final or total canopy is important, this is the land cover before the harvest of the plant. Instead of using the canopy of the plant also the Leaf Area Index (LAI) – total leaves area/unit of ground surface - can be used. Based on this index the canopy can be determined. The LAI and the canopy are related to each other. Hemp has one of the highest Leaf Area Index. The leaf area of any variety tested exceeded 4-5 times the ground area covered, and due to higher rate of leaf development, shaded out any weed development (Vallaint-Saunders, 2013). The International Hemp Association published in name of Lisson and Mendham (2015) a study to the growth of hemp. They found on average a LAI 4.25 (Lisson & Mendham, 2015).

- The initial canopy cover of a field of industrial hemp haves a minimum of 3.75%. This is corresponding with a *very high cover* in the model. This high value of the initial canopy cover is based of researcher's recommendations; they recommend a minimum seeding rate of 250 seeds per m^2, which is equal to 2,500,000 seeds per hectare (Baxter & Scheifele, 2009).
- The maximum canopy is 96%, corresponding to *almost entirely covered* in AquaCrop. This is in conformity with a LAI of 4 – 5 (Vallaint-Saunders, 2013) or 4.25 (Lisson & Mendham, 2015) as stated in a report of Huemmrich (2013). In this report he figured out what the relationship is between the Leaf Area Index and the canopy cover of a crop, the results of this investigation is showed in graphs and based on that graphs the 95% is concluded (Huemmrich, 2013). Also could these be concluded based on two different ways to convert the LAI to the CC (Canopy Cover)
    - Garcia, et al (2009):

$$CC = \frac{1 - e^{-\frac{LAI}{1.3}}}{1 + e^{-\frac{LAI}{1.3}}} = \frac{1 - e^{-\frac{4.25}{1.3}}}{1 + e^{-\frac{4.25}{1.3}}} = 0.96$$

    - Hsiao, et al (2012):

$$CC = 1.005[1 - e^{-0.6*LAI}]^{1.2} = 1.005[1 - e^{-0.6*4.25}]^{1.2} = 0.96$$

  So based on these two conversion and the reading of the graph can be concluded that the canopy cover of industrial hemp is 96%.

- Climate and soil depends on the location of crop production. The soils of the locations are showed in Table 3 (Koirala, 2015).
- The industrial hemp is mature and flowering after 110-130 days (Kraenzel, et al., 1998), but the maximum canopy cover of the industrial hemp plant is after about 70-90 days when the crop is ready the harvest if the industrial hemp is used for fibre production (Kraenzel, et al., 1998). For AquaCrop these two characteristics are implanted with 80 days for maximum canopy cover and 120 days for maturity. Figure 8 shows a print screen of how this is implemented in the AquaCrop model.

3.1.2 Green Water footprint - Implementing industrial hemp in AquaCrop

All the parameters of the industrial hemp are summarized in Table 4. For each country the growing of the industrial hemp is simulated ones.

TABLE 4. SUMMARY OF THE USED DATA FOR THE SIMULATIONS IN AQUACROP

Data	Value	Source
P, ET, T_{min}, T_{max}	Differ on location, see source	CLIMWAT (FAO, 2013)
Sowing data	Depends on rainfall criterion. Crop needs rainfall to germinate	(British Columbia Ministry of Argiculture and Food, 1999)
Initial Canopy Cover (CC_0)	Seeding rate: 250 seeds/m^2	(Baxter & Scheifele, 2009)
Canopy Cover (CC)	96%	(Huemmrich, 2013) (Garcia-Vila, et al., 2009) (Hsiao, et al., 2012)
Growing cycle	Maximum Canopy: 70 – 90 days Maturity: 120 days	(Kraenzel, et al., 1998)
Harvest Index (HI)	Assumption: 35%	(Hsiao, et al., 2012)
Soil water stresses (K_s)	Tolerant to water stresses: p(upper) 0.30, p(lower) 0.65	(British Columbia Ministry of Argiculture and Food, 1999) AquaCrop (FAO, 2015)
WP*	15 g/m^2	• (Hsiao, et al., 2012) says WP* = [10 – 20 g/m^3] • (El Bassam, 1998) says hemp = C3 crop • I assume WP* = 15 g/m^3
Soil type	Differ on location, see source	University of Tokyo (Koirala, 2015)
Irrigation	Rainfed	(Lisson & Mendham, 2015)
Other parameters	Default values in AquaCrop as for barley	AquaCrop

After implementing all the characteristics of the industrial hemp crop and the data about the soil and climate running the model in AquaCrop is the next step to determine the green WF of industrial hemp. The model gives a lot of information about the growing process of the crop. Because AquaCrop just modelled the soil-water balance and the plant-growth the WF cannot directly gathered from results of the model run. Among the AquaCrop results there are the evapotranspiration (ET) and the yield (y) of the crop, based upon these the green WF (m^3/ton) can be calculated with the following equation (Hoekstra, et al., 2011). In the case of industrial hemp the ET is fully from green water resources, because there is no irrigation needed, this ET_0 is equal to ET_{green}.

$$WF_{green}\ (m^3/ton) = ET_g/y$$

$$ET_g = evapotranspiration\ from\ green\ water\ resources\ (mm)$$

$$y = yield\ (ton/ha)$$

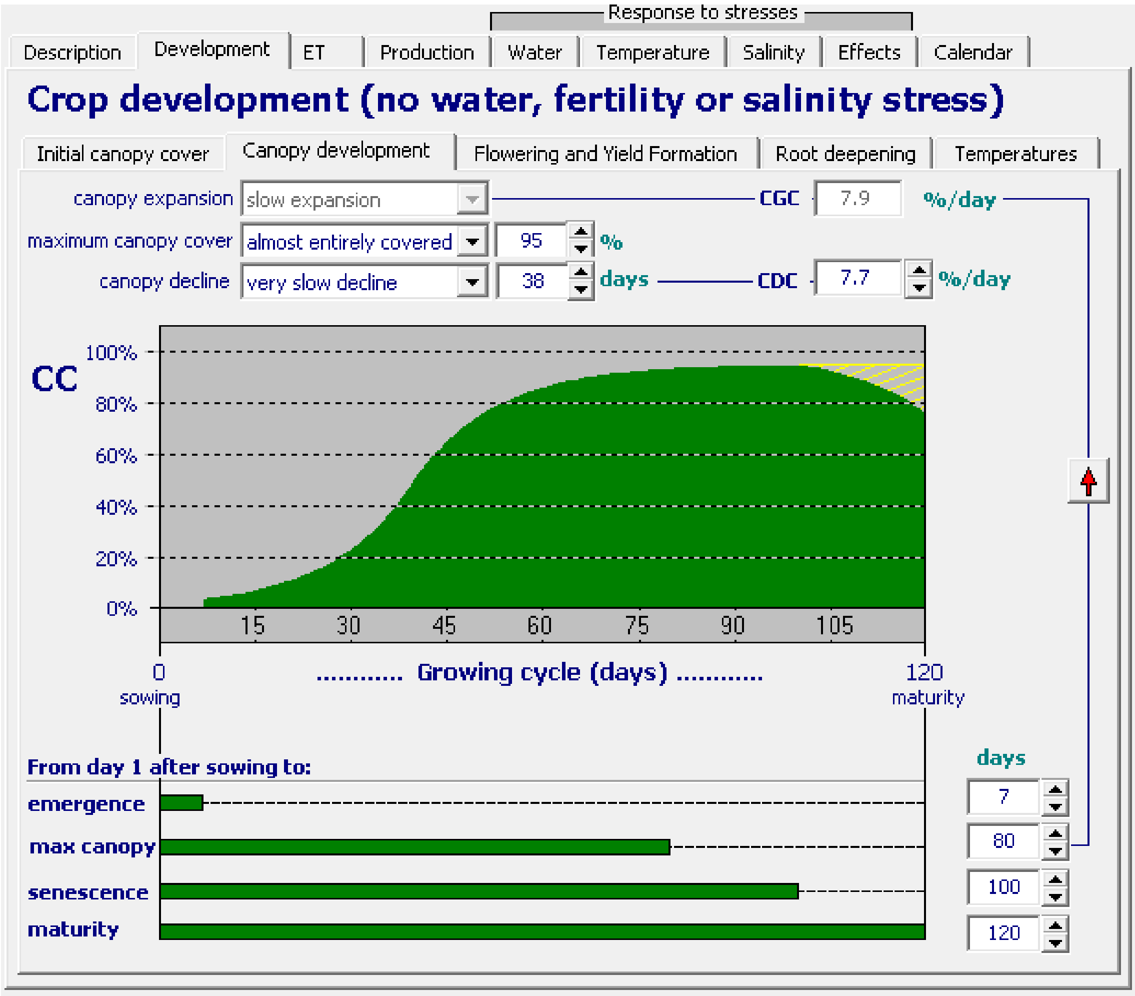

FIGURE 8. IMPLEMENTATION OF DAYS AFTER SOWING TO MAXIMUM CANOPY COVER AND MATURITY OF THE INDUSTRIAL HEMP PLANT

3.1.3 Grey Water footprint

The calculation of the grey WF is based on the use of fertilizers during the growing cycle of the industrial hemp. The grey WF depends on the amount and kind of fertilizer that is used to optimize the yield and biomass production of the crop. The grey WF is calculated by the following equation (Hoekstra, et al., 2011):

$$WF_{grey} = \frac{L/c_{max}}{y * A}$$

$$L = \alpha * AR$$

$\alpha = leaching\ rate$ (%)

$AR = Application\, rate\ (kg/ha)$

$c_{mx} = maximum\ concentration\ of\ fertilizers$ (%)

$y = yield\ (ton/ha)$

$A = production\ area\ (ha)$

3.2 Water footprint of industrial hemp based products

For the calculations of the water footprint of the different fraction products of hemp the method of Hoekstra et al (2011) will be followed. Before we calculate the water footprint of a product first the definition of it: the water footprint of a product (in this case textile from the hemp plant) is the total volume of fresh water that is used directly or indirectly to produce the product. It is estimated by considering water consumption and pollution in all steps of the production chain. The water footprint of a product breaks down into a green, blue and grey component (Hoekstra, et al., 2011). Once harvested the hemp crop has a high yield of cellulose, edible proteins, oils and fibres with over 25,000 different product applications across a whole array of industries (Hemp Ethics, 2015). Because of this the 'chain-summation approach' for the calculation cannot be used, this approach can only be applied in the case where a production system produces one output (Hoekstra, et al., 2011). So the 'stepwise accumulative approach' (Hoekstra, et al., 2011) will be used for the calculation of the water footprint of the products of hemp. In the 'stepwise accumulative approach', the calculation is based on the water footprints of the inputs needed at the last processing step. The water footprint of output product *p* is calculated as (Hoekstra, et al., 2011):

$$WF_{prod}[p] = \left(WF_{proc}[p] + \sum_{i=1}^{y} \frac{WF_{prod}[i]}{f_p[p.i]} \right) \times f_v[p]$$

in which $WF_{prod}[p]$ is the water footprint (volume/mass) of output product *p*, $WF_{prod}[i]$ the water footprint of the input product *i* and $WF_{proc}[p]$ the process water footprint of the processing step that transforms the *y* input products into the *z* output products, expressed in water use per unit of processed product *p*. Parameter $f_p[p.i]$ is a so-called 'product fraction' and parameter $f_v[p]$ is a 'value fraction'.

3.2.1 Product tree, product fraction and value fraction

Important issue to tackle in this study to define proper numbers for the product and value fractions. How and where to obtain these fractions? For the value fraction possibly the global market prices can be used. Vantreese (1997) did a research to the global market and prices of hemp and hemp related products. Based on this study probably proper value fraction of hemp can be determined. Also in 2013 the Department of Agricultural Economics of the University of Kentucky did a study to the market and the prices of hemp and hemp related products, they were focussing on the hemp market within the US, also this research results in interesting and useful information about the composition of the market of hemp and the related product including their economic value (Department of Agricultural Economics, University of Kentucky, 2013). In a research of Johnson (2015) is an interesting table which shows prices and market shares of different kinds of sub products of hemp.

Finding information to determine the product fraction of the sub products of hemp is much harder. These values are much more based on observations and experiences. Probably the product fractions of the hemp related products can be determined by a detailed analysis of the data that is available about the production of hemp and the production and trade of hemp related products. For example the FAO has information about the total global production of hemp (FAOSTAT, 2015). But also more specific information about hemp products are available, the earlier mentioned study of Johnson (2015) shown a helpful and interesting table with data about the trade of hemp related products within the US. Based on the existing knowledge (Conde , 2015); (Ren, 2000); (USDA, -), the data of production and trade and results of observations and experiences it should be possible the provide numbers of the product fractions.

Figure 10 is the product tree of hemp wherein are the crop derived products of industrial hemp are shown. After further investigation the values of the product and value fraction should all have a value between 1.00 (100%) and 0.00 (0%). In the product tree is also a sub product residue. For example the roots and the leaves of the hemp plant are part of this. We made the assumption that the product fraction and value fraction of this is 0.00. Despite that the roots and leaves of the hemp plant feed the soil with valuable nutrients the values of this is hardly not to measures. Besides this, the residue of the plant don’t have a very strong influence on the total water footprint of the hemp production and it is unknown what exactly are all the other uses of the hemp plant which all are included in the residue sub product. Therefore the assumption to neglect the value of the residue sounds justifiable. The other product and value fraction are based upon the earlier mentioned reports wherein the trade and production of industrial hemp is investigated.

Also the different products are shown, these are related to the 9 above mentioned submarkets of the industrial hemp market (see Figure 5). The used product groups in the product tree need some explanation (Hemp Technologies, 2015).

- Textiles from bast fibre are apparel, fabrics, bags, shoes and socks
- Technical textiles from bast fibre are cordage, netting, canvas and carpeting
- Industrial products from bast fibre are geotextiles, bio-composite pultrusion, compression and moulding
- Hemp as building material from hurd makes fibre board, isolation and hempcrete
- Industrial products from hurd are used for animal bedding, mulch, boiler fuel and chemical absorbent
- Paper from hurd are used for printing, cigarette filters, newsprint, packaging, cardboard, netting, canvas and carpeting
- Foods that came from the hemp nut are bread, granola, ice cream, milk, cereals and protein powder.
- Foods that contains the hemp oil are salad oils, efa food, supplements, margarine and sauté oil
- Body care products from the hemp oil are soap, shampoo, hand cream and cosmetics
- Technical products that contains hemp oil are oil paints, solvents, varnish, lubricant,

printing ink, diesel fuel and coatings.

3.2.2 Process Water footprint of textile fibres from industrial hemp

To determine the process WF for the production of textile fibres from industrial hemp are the steps in the process from plant to fibre important.

Figure 9 shows the process steps for the textile fibres from industrial hemp. From this figure the total processing WF from producing textile fibres from industrial hemp is 158.5 m^3/ton of industrial hemp textile. The greater part, 122.5 m^3/ton is needed for the retting of the bast fibre, 36 m^3/ton is needed for the bleaching of the fibres (Van de Werf & Turunen, 2008).

Harvesting	
The crop is harvested when the fiber is at its highest quality	WF_{proc} = 0 m^3/ton

Retting & decorticating	
Separating the bast fibre from the rest of the stalk (retting) and separating the short and the long fibres (decortitating)	WF_{proc} = 122.5 m^3/ton*

Wet processing	
Bleaching, dying (colouring) and printing of the industrial hemp fibres	WF_{proc} = 36 m^3/ton*

Finishing	
Processing the fibres to the final textile	WF_{proc} = 0 m^3/ton

FIGURE 9. PROCESS STEPS FOR THE PRODUCTION OF TEXTILE FIBRE FROM INDUSTRIAL HEMP, A TOTAL WF OF 158.5 M^3/TON OF INDUSTRIAL HEMP TEXTILE; * SOURCE: (VAN DE WERF & TURUNEN, 2008)

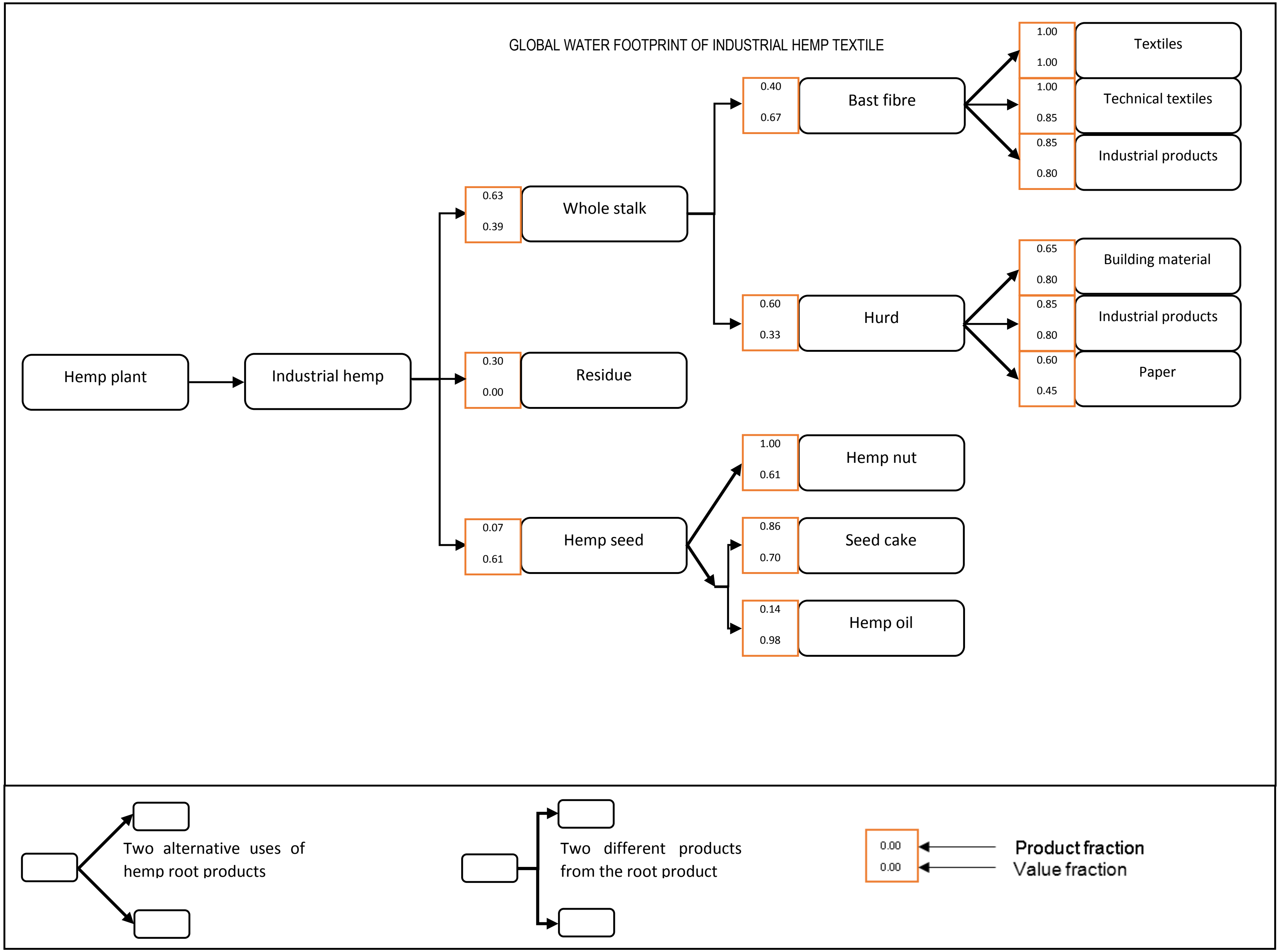

FIGURE 10. PRODUCT TREE OF INDUSTRIAL HEMP WITH ITS PRODUCT AND VALUE FRACTION OF THE INDUSTRIAL HEMP DERIVED CROP PRODUCTS

3.3 Industrial hemp textile vs. cotton textile

For the comparison between hemp and cotton the water footprint is the most important. Especially the water footprint of textiles from the two plants. The water footprint of cotton fibres is 10,000 litres/kg (Hoekstra, 2013). The water footprint of cotton fibres is substantially larger than the water footprints of sisal and flax fibres, which are again larger than the water footprint of jute or hemp fibres (Mekonnen & Hoekstra, 2011). Mekonnen and Hoekstra (2011) found in their research that true hemp fibres has a global average water footprint of 2,719 m^3/ton (2,719 litres/kg).

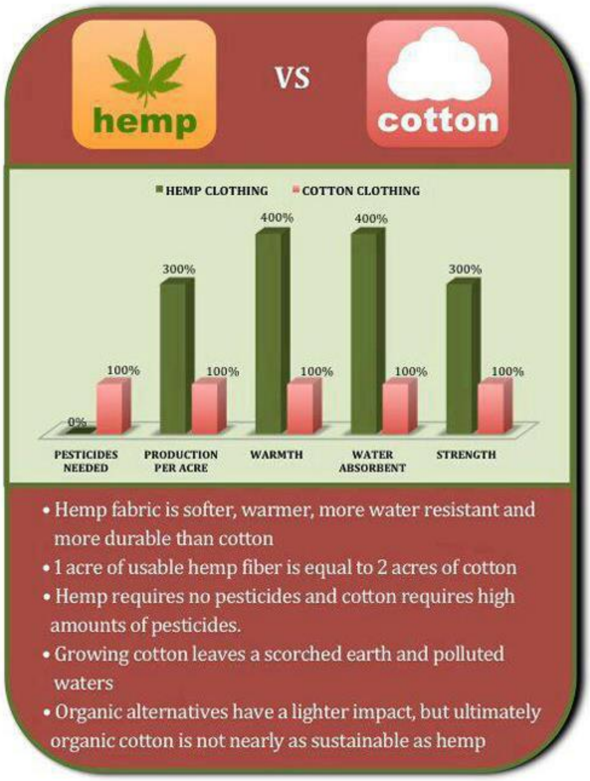

FIGURE 11. COMPARISON BETWEEN HEMP AND COTTON TEXTILE (HOLTERMAN, 2015)

Besides the differences in the water footprint between the cotton and hemp fibres their also other differences in the clothes that are made of these products. These differences are summarized in Figure 11. Holterman (2015) stated in their online article that 'hemp beats cotton in a number of areas as a clothing product'. This is based on the following arguments for the comparison of hemp and cotton: hemp is four times softer, hemp is three to eight times stronger, hemp is much more durable, hemp is flame retardant, hemp is not affected by UV rays, hemp is very breathable but also very moisture absorbent.

3.4 Reflection on AquaCrop

Facing growing water scarcity, declining water quality, and uncertainties of climate change and climate variability, improving efficiency and productivity of crop water use, with the simultaneous reduction of negative environment impact, are of utmost importance to respond to the increasing food demand of the growing world population (Hoekstra, 2013). To address food security and assess crop production as affected by environment and management, a large number of crop simulation models were developed over the last four decades. These models often require a large number of input variables and parameter values that are not easily available for the diverse range of crops and environments worldwide. Furthermore, insufficient transparency is often a strong constraint for extension services practitioners, consulting engineers, governmental agencies, NGOs and farmer associations (Vanuytrecht, et al., 2014). To deal with this limitations, the Food and Agriculture Organization of the United Nations (FAO) has developed AquaCrop as a model that seek a balance among simplicity, accuracy and robustness (Heng, et al., 2009).

The AquaCrop model is a user-friendly and practitioner-oriented type of model, and requires a relatively small number of parameters (Heng, et al., 2009). AquaCrop simulates daily biomass production and final crop yield in relation to water supply and consumption and agronomic management, based on current plant physiological and soil water and salt budgeting concepts (Vanuytrecht, et al., 2014).

Figure 12 shows the calculation scheme of the AquaCrop model (Vanuytrecht, et al., 2014). The detailed explanation of the working and the calculation scheme of the model is described by Vanuytrecht, et al. (2014). Also the manual of the AquaCrop model (Chapter 2 and 3) gives a lot of information about the working of the model (Raes, et al., 2012a) and gives an explanation of the calculation procedures within the AquaCrop model (Raes, et al., 2012b).

AquaCrop is a water-driven dynamic model that is able to simulate the attainable yield of herbaceous crops under various management and environmental conditions by using relative few conservative crop parameters and a small number of input variables. Although the model has already been tested and applied in various regions, efforts and continuously made to further improve the simulations of yield and water use by introducing new concepts and model equations, without jeopardizing the simple approach of the model and the transparency of the simulation (Vanuytrecht, et al., 2014).

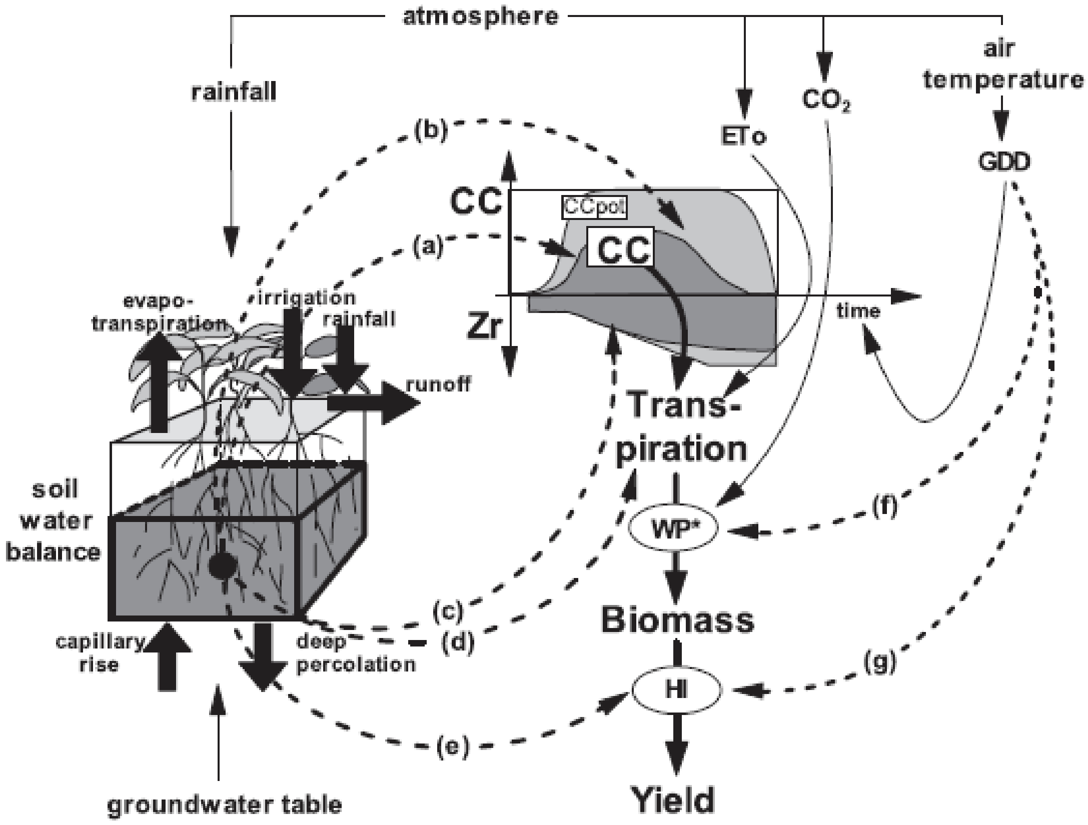

FIGURE 12. CALCULATION SCHEME OF AQUACROP WITH INDICATION (DOTTED ARROWS) OF THE PROCESS AFFECTED BY WATER STRESS (A - E) AND TEMPATURE STRESS (F TO G). CC IS GREEN CANOPY COVER; ZR, ROOTING DEPTH; ET0, REFERENCE EVAPOTRANSPIRATION; WP, NORMALIZED BIOMASS WATER PRODUCTIVITY; HI, HARVEST INDEX; AND GDD, GROWING DEGREE DAY. WATER STRESS: (A) SLOWS CANOPY EXPENSION, (B) ACCELERATES CANOPY SENESCENCE, (C) DECREASES ROOT DEEPENING BUT ONLY IF SEVERE, (D) REDUCES STOMATAL OPENING AND TRANSPIRATION, AND (E) AFFECTS HARVEST INDEX. COLD TEMPERATURE STRESS (F) REDUCES BIOMASS PRODUCTIVITY. HOT OR COLD TEMPARATURE STRESS (G) INHABITS POLLINATION AND REDUCES HI (VANUYTRECHT, ET AL., 2014)

4 RESULTS

The results of determination of the global Water footprint of industrial hemp is divided in three parts: the green, blue and grey Water footprint of industrial hemp. Beside the determination of the total WF also the WF of derived crop products of industrial hemp are calculated. Third the results of the comparison with cotton will be showed.

4.1 The global Water footprint in the hemp growing stage

4.1.1 Green Water footprint in the hemp growing stage

After implementing the industrial hemp in AquaCrop program running the model for the different locations of the hemp production. The results of the runs for the top-ten industrial hemp producing countries are shown in Table 5. This table shows the regions wherefore the model runs and what are the results of these runs for these specific locations. From this can be concluded that in the top-ten hemp producing countries the green Water footprint (WF) varies from approximately 415 m^3/ton in the Netherlands until approximately 5,300 m^3/ton in the Turkey. For determining the green Water footprint of the crop two output parameters are necessary: yield (in tonnes) and evapotranspiration (ET; in mm.). Based on these two parameters the green WF is calculated for the specific locations of hemp production. The green WF is calculated by the following equation (Hoekstra, et al., 2011). The ET need to be converted to an amount in cubic meters water (the amount in mm need to be multiplied by 10; divided by 1,000 to get meters and multiplied by 10,000 the amount of water per hectare).

$$WF_{green} = ET_0/yield$$

TABLE 5. OUTPUT OF THE MODEL RUNS IN AQUACROP AND THE CALCULATED GREEN WATER FOOTPRINT OF THE TOP-TEN HEMP PRODUCING COUNTRIES

Country	Yield*(1) (ton/ha)	ET_0*(2) (mm)	Green Water footprint (m^3/ton)
China	2.01	363.8	1,810.0
Korea	0.67	418.1	2,446.3
Romania	2.3	470.6	2,046.1
USSR	0.4	348.9	3,085
Netherlands	7.5	312.3	416.4
Chile	0.95	66.9	704.2
Spain	3.66	509.0	1,390.7
Turkey	1.12	596.1	5,322.3
Austria	6.25	377.8	604.5
Ukraine	0.53	382.3	7,213.2

*(1) Source: (FAOSTAT, 2015)

*(2) Source: output of simulation in AquaCrop

Based on these calculated Water footprints of the top-ten hemp producing countries the worldwide averaged green WF of industrial hemp can be determined. Therefore also the production data of these countries are needed (Table 2). The worldwide green WF of hemp is based on weighted average of the worldwide production of hemp. So for each producing country their fraction of the worldwide hemp production is calculated. An assumption that is made is that the total production of the top-ten hemp producing countries is representative of the total worldwide production of industrial hemp (in reality the top-ten hemp producing countries produces 94.8% of the worldwide production, see Table 2).

Table 6 shows the calculated fractions of the worldwide hemp production. These values are multiplied with green WF of each hemp producing country, what results in the green WF fraction per hemp producing country from the total worldwide green WF of industrial hemp. The global average green WF of industrial hemp is equal to the sum of green WF fractions of the country; the global average green WF of industrial hemp is 1922.1 m^3/ton.

TABLE 6. PRODUCTION FRACTIONS AND THE CALCULATION OF THE GLOBAL AVERAGE GREEN WATER FOOTPRINT OF INDUSTRIAL HEMP

Country	Green WF (m^3/ton)	Production*(1) (ton/yr)	Fraction worldwide production (-)	Green WF fraction (m^3/ton)
China	1,810.0	25,687.4	0.39	711.7
Korea	2,446.3	12,195.6	0.19	456.7
Romania	2,046.1	5,927	0.09	185.6
USSR	3,085	5,060	0.08	239.0
Netherlands	416.4	4,254.5	0.07	27.1
Chile	704.2	4,171.7	0.06	45.0
Spain	844,3	4,003.2	0.06	51.7
Turkey	5,322.3	1,609.9	0.02	131.2
Austria	604.5	1223	0.02	11.3
Ukraine	3,439.6	1,191.1	0.02	62.7
TOTAL		**65,323.4**	**1.00**	**1,922.1**

*(1) Source: (FAOSTAT, 2015)

4.1.2 Blue Water footprint in the hemp growing stage

The blue WF depends on the amount of irrigation of the crop. The dry mass production and yield of industrial hemp do not increase due to any amount of irrigation (Lisson & Mendham, 2015). Therefore the blue WF of industrial hemp is zero. This is in according with the results of the research of Mekonnen & Hoekstra to the green, blue and grey WF of several different crops and derived crop products (2010). In their research they also concluded a blue WF of hemp of zero.

4.1.3 Grey Water footprint in the hemp growing stage

The grey Water footprint is calculated based on the data of used fertilizers. To improve the yield of the industrial hemp only nitrogen is important (Vera, et al., -). Increased nitrogen fertilizer rates significantly increased yield and biomass production. The use of other fertilizers like phosphorus don't increase the production. The application of seed-placed phosphorus fertilizer significantly reduced emergence, yield and biomass, especially in a dry year (Vera, et al., -). Applying nitrogen-based fertilizers has proven very effective in increasing yields. The optimal nitrogen fertilizer rate for a better biomass production of industrial hemp is 150 kg/ha (Sausserde & Adamovics, 2013).

The equation that is used to calculate the grey WF follows (Chico, 2014):

$$WF_{grey} = \frac{L/c_{max}}{y * A}$$

- The average leaching rate for nitrogen is 10% (Chico, 2014); $\alpha = 10\%$
- The application rate is 150 kg/ha (Sausserde & Adamovics, 2013); $AR = 150$
- The c_{max} depends on the ambient water quality standards. For nitrogen this is 10 mg/l (EPA, 2009); $c_{max} = 10$
- The yield (y) and production area (A) depends on the locations of industrial hemp producing, these data is shown in Table 2 (FAOSTAT, 2015).

Table 7 shows the result of the calculation of the global grey WF of industrial hemp. The grey WF of industrial hemp differ over the top-ten hemp producing countries. With a grey WF 100 m^3/ton the Netherlands haves the lowest grey WF, in the USSR the grey WF is the highest; 1,875 m^3/ton. Based on the fractions of the worldwide industrial hemp productions the fraction of each of the hemp producing countries is calculated, the sum of these fractions is the global average of the grey WF. So can concluded that the global grey WF of industrial hemp is 645 m^3/ton.

TABLE 7. CALCULATION OF THE GLOBAL GREY WATER FOOTPRINT OF INDUSTRIAL HEMP

Country	**Production*(1) (ton/yr)**	**Yield*(1) (ton/ha)**	**A*(1) (ha)**	**grey WF (m^3/ton)**	**Fraction worldwide production (-)**	**Grey WF (m^3/ton)**
China	25,687.4	2.01	12,780	373.1	0.39	146.7
Korea	12,195.6	0.67	18,202	1,119.4	0.19	209.0
Romania	5,927	2.3	2,577	326.1	0.09	29.6
USSR	5,060	0.4	12,650	1,875.0	0.08	145.2
Netherlands	4,254.5	7.5	567	100.0	0.07	6.5
Chile	4,171.7	0.95	4,391	789.5	0.06	50.4
Spain	4,003.2	3.66	1,094	204.9	0.06	12.6
Turkey	1,609.9	1.12	1,437	669.6	0.02	16.5
Austria	1,223	6.25	196	120.0	0.02	2.2
Ukraine	1,191.1	0.53	2,247	1,415.1	0.02	25.8
TOTAL						**644.6**

α (-)	0.10
AR (kg/ha)	150
c_max (mg/l)	10

*(1) Source: (FAOSTAT, 2015)

4.1.4 Total Water footprint of hemp growing

The total WF is a combination of the global green, blue and grey WF of industrial hemp, summed up over the hemp growing stage and the processing stage. The total WF can be calculated with the following equation (Hoekstra, et al., 2011):

$$WF_{total} = WF_{green} + WF_{blue} + WF_{grey}$$

$$WF_{green} = 1{,}922.1\ m^3/ton$$

$$WF_{blue} = 0\ m^3/ton$$

$$WF_{grey} = 644.6\ m^3/ton$$

$$WF_{total} = 1{,}922.1 + 0 + 644.6 = 2{,}566.7\ m^3/ton$$

Based on the calculation above can concluded that the total global Water footprint of industrial hemp is about 2,570 m^3/ton.

4.2 Water footprint of industrial hemp based products

The WF of industrial hemp based products is based on the product and value fractions and the process WF of the production chain of the industrial hemp based product. The WF the processing is added in the last step of the calculation, this because the WF of processing is given in m^3/ton of industrial hemp textile.

Based on the values of Figure 10 the following calculation are made.

1. WF of industrial hemp: 2,566.7 m^3/ton
2. WF of whole stalk: $WF = \frac{WF\ of\ ind.hemp * f_v[p]}{f_p[p.i]} = \frac{2{,}566.7*0.39}{0.63} = 1{,}588.9\ m^3/ton$
3. WF of bast fibre: $WF = \frac{WF\ of\ whole\ stalk * f_v[p]}{f_p[p.i]} = \frac{1{,}588.9*0.67}{0.40} = 2{,}661.4\ m^3/ton$
4. WF of industrial hemp textile:

$$WF\ (industrial\ hemp\ textile) = WF_{proc}[p] + \frac{WF\ of\ bast\ fibre * f_v[p]}{f_p[p.i]}$$

$$= 158.5 + \frac{2{,}661.4 * 1.00}{1.00} = 2{,}819.9\ m^3/ton$$

Based on the above calculation the conclusion can made that the global WF textile fibres from industrial hemp haves a total of approximately 2,800 m^3/ton. This is divided in the green, blue and grey WF:

- WF_{green}: 1,993.0 m^3/ton
- WF_{blue}: 158.5 m^3/ton
- WF_{grey}: 668.4 m^3/ton

4.3 Industrial hemp vs. cotton

The comparison between industrial hemp and cotton is based on a few elements. In the following the paragraphs the similarities and differences on the global WF, locations of production and water scarcity.

4.3.1 Water footprint

First of all is the comparison between industrial hemp and cotton based textile fibres based on the global WF of these two products. As calculated the WF of textile fibres from industrial hemp are about

2,800 m^3/ton. Hoekstra (2013) investigated the WF of cotton lint and concluded a WF of 10,000 m^3/ton. So the WF for the production of cotton is more than three times larger. This large difference in the total WF is based on the WF for the production of the crop, the WF of the processes of both are more or less in the same order of magnitude (Chapagain, et al., 2005). The large WF of cotton lint is due to high water requirements of the crop for growing, this results in a high green and blue WF. Besides this, the cotton also needs a lot of fertilizer to get the optimum yield (Chapagain, et al., 2005).

4.3.2 Locations of production

For the determination of the global WF of industrial hemp Figure 7 was not precise enough to determine the regions of production of industrial hemp. But to get an overview of the global production locations of industrial hemp in comparison with the global production locations of cotton (Ramankutty, 2013) this can be used. Figure 13 shows the crop maps of industrial hemp (in yellow) and cotton (in blue) together. From this can be concluded that cotton globally is grown more south than industrial hemp. This is related to the requirements of the two crops of climate, soil, etc. (Martino, 2013).

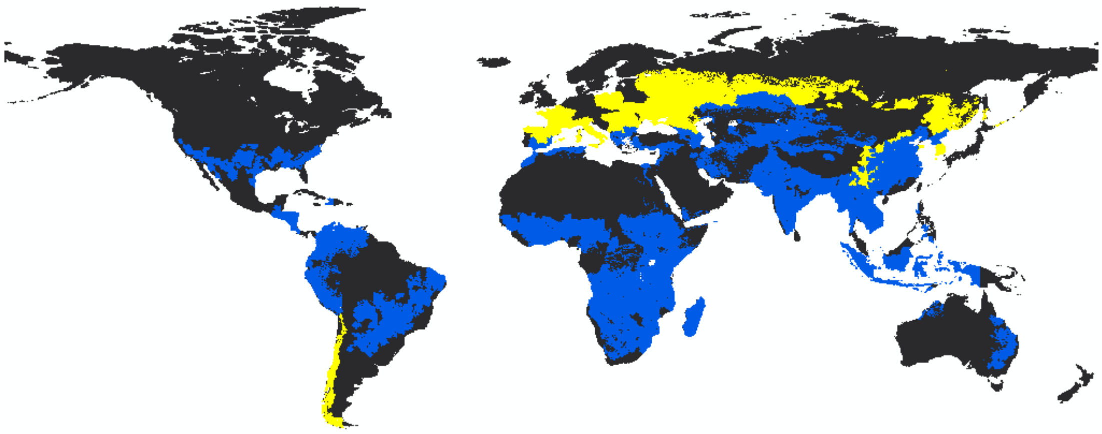

FIGURE 13. CROP MAPS OF INDUSTRIAL HEMP (IN YELLOW) AND COTTON (IN BLUE); DATA FROM RAMANKUTTY (2013)

4.3.3 Water scarcity

One the notable characteristics of cotton is that it tends to be grown in parts of the world were water is scarce (Palmer, 2011). Due to the large WF of cotton the water scarcity in the areas of cotton production will increase, which will result in more negative effects for environment and humanity. The earlier mentioned Aral Sea region is an exceptional example of cotton production in a water scarce area.

Figure 14 shows a map of the global water scarcity (FAO, 2007). If this map is compared with the results of crop maps of industrial hemp and cotton (Figure 13) can be concluded that cotton much more in produced in water scarce area. The red and orange parts of the map (Figure 14) are the area where water scarcity occurs. This areas are mainly concentrated in the continents Asia and Africa, what corresponds with the main areas of cotton production. The greater part of the region of industrial hemp production are in the blue regions of Figure 14; this corresponds with areas with a little or no water scarcity.

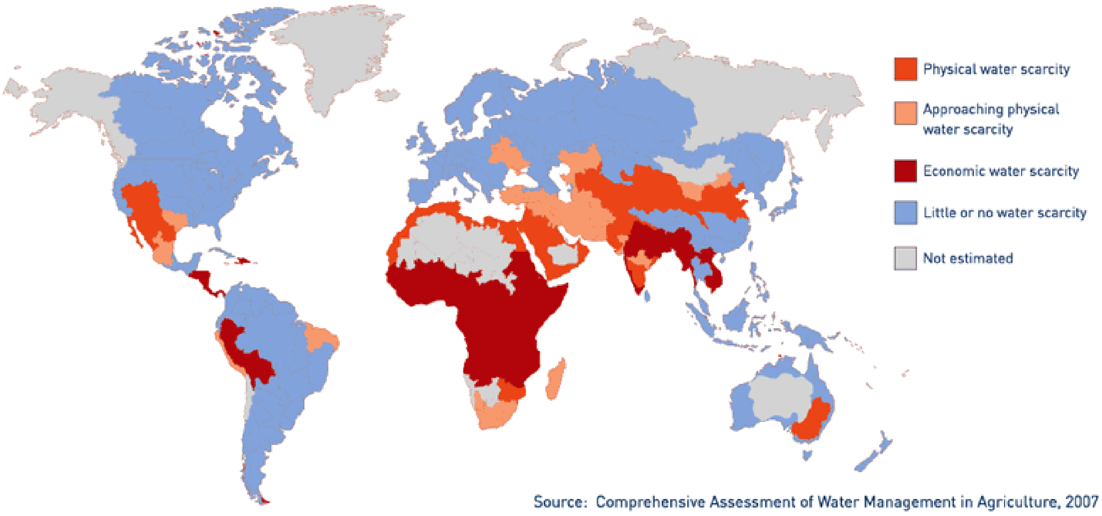

FIGURE 14. GLOBAL WATER SCARCITY MAP; RED AND ORANGE MEANS WATER SCARCITY, BLUE ARE THE REGION WITH A LITTLE OR NO WATER SCARCITY (FAO, 2007)

5 DISCUSSION

The discussion about the research to the WF of industrial hemp textiles is splitted up in three parts. In general the method and results are discussed. In addition are in the following paragraphs the limitations and recommendations of the research are discussed.

5.1 General

According to the used method and the results of the investigation the following issues are noticed:

- The water footprint that is resulted from this study corresponds with earlier investigations. The green, blue and grey water footprint of industrial hemp are all in the same order of magnitude. Also the total water footprint of industrial hemp textile is more or less in the same order of magnitude as in earlier investigations
- In a study of Mekonnen & Hoekstra (2011) they are using CROPWAT to simulate the growing stage of industrial hemp. The results of this study is for the global average WF quite the same:
    - Green WF: 1,824 m^3/ton (Mekonnen & Hoekstra, 2011) and 1,922 m^3/ton in this study
    - Blue WF: 0 m^3/ton (Mekonnen & Hoekstra, 2011) and 0 m^3/ton in this study
    - Grey WF: 624 m^3/ton (Mekonnen & Hoekstra, 2011) and 645 m^3/ton in this study

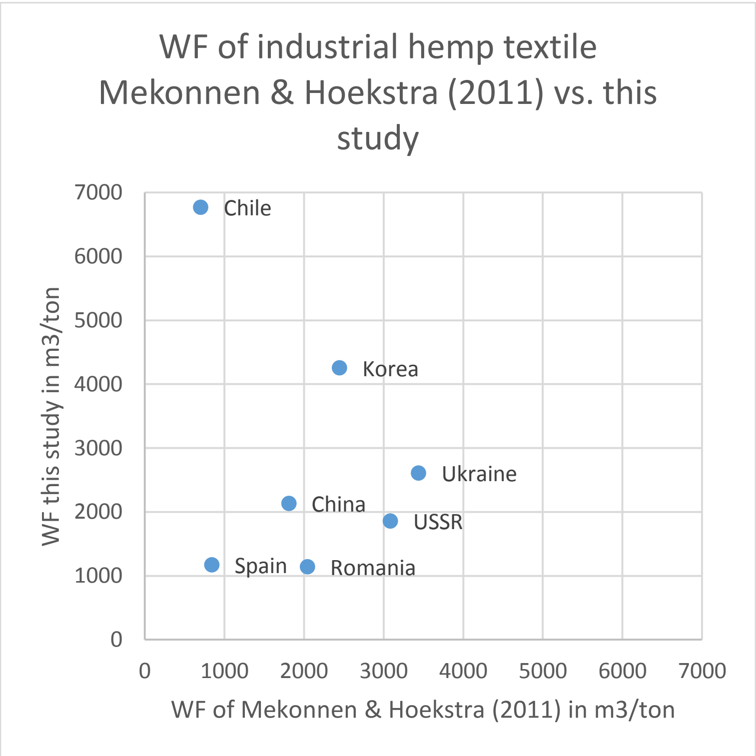

FIGURE 15. COMPARISON BETWEEN THE RESULTS OF THE WF OF INDUSTRIAL HEMP TEXTILE FROM THE STUDY OF MEKONNEN & HOEKSTRA (2011) AND THIS STUDY FOR 7 OF TOP-TEN HEMP PRODUCING COUNTRIES

But for the WF of industrial hemp textile per country there is no correlation in the results. Figure 15 shows the comparison of the results between this study and the study of Mekonnen & Hoekstra (2011). The dotted line is the trendline of the results of this comparison. Based on Figure 15 the conclusion can made that within countries the results of the WF of industrial hemp textile of these two studies don't have a correlation. In this comparison only taken into account the countries from the top-ten hemp producing countries which have data in both studies.

- This investigation is more detailed than the existing studies to the water footprint to industrial hemp. Herein is looked at very specific regions where industrial hemp is produced. Therefore all data that is used was relevant for these specific locations (temperature, evaporation, soil, etc.).

If industrial is going to produce at larger scale following the increase of demand for industrial hemp textile the price of industrial hemp stalks compared to industrial hemp seeds will go up; the value fractions of stalks in the product tree of industrial hemp will increase. The result is that a larger part of the WF of industrial hemp growing will be allocated to the industrial hemp textile. If the demand to industrial hemp textile will growing very fast and the demand of the industrial hemp seeds is not changed the WF of industrial hemp textile will increase also very fast and the difference with cotton textile will decrease.

There are also differences between the yield of FAOSTAT (2015) and the simulated yield from AquaCrop. In Table 8 the values of both are shown. For some countries larger differences could be noticed. The higher values of the yield from AquaCrop, for example in the countries Republic of Korea, USSR and Ukraine can be explained by the circumstances in the country. The yield of FAOSTAT is based on the real situation. The much higher yields of the simulations from AquaCrop are probably due to incorrect assumption of the characteristics of the crop whereby the yield of the industrial hemp is overestimated. Also is the model an optimal situation, whereby higher yields will occur. That the FAOSTAT (2015) yield sometimes is higher than the simulated yield of the industrial hemp crop may be due to deviating circumstances and conditions on the locations of hemp producing. The real situation on the location of hemp production could be better than the average situation in that region that is used for the simulation in AquaCrop.

TABLE 8. COMPARISON OF THE YIELD FROM FAOSTAT AND THE SIMULATED YIELD FROM AQUACROP

Country	**Yield (ton/ha) from FAOSTAT** (2015)	**Simulated yield ton/ha) from AquaCrop**
China	2.01	2.17
Republic of Korea	0.67	4.15
Romania	2.3	2.80
USSR	0.4	2.80
Netherlands	7.5	4.04
Chile	0.95	1.73
Spain	3.66	1.05
Turkey	1.12	0.99
Austria	6.25	4.13
Ukraine	0.53	4.20

5.2 Limitations

During the investigation of the water footprint of industrial hemp textile some limitations for getting the best results popped up.

- Industrial hemp is globally seen a very little produced crop. Thence there is just limited data of industrial hemp production available. There are no large databases for a kinds of data that is required, therefore the data is gathered by a large number of reports, website and studies. But these maybe are not totally coherent with each other.
- Industrial hemp was not available in AquaCrop. So the characteristics of industrial hemp are applied in the model by changing the characteristics of barley.
- Using a model to determine the water footprint is an approximation of the reality, but it never 100% match with reality. So the results of the study should therefore always be interpreted with this in mind.

6 CONCLUSION

The conclusion of the research the global water footprint of industrial hemp textile is based on the goals and objectives that are pre-set on the investigation. The main goal of the research was to determine the water footprint of industrial hemp textiles. The three points below are the summarized objectives of the study to the water footprint of industrial hemp textiles. These three points are discussed more detailed in the next few paragraphs.

- Calculating the water footprint of the industrial hemp crop with the AquaCrop model
- Understanding the processing chain and determining the water footprint of industrial hemp textile
- Making the comparison between industrial hemp and cotton textile

6.1 Water footprint of industrial hemp based on AquaCrop

After implementing the characteristics of industrial hemp in the AquaCrop model the green water footprint of industrial hemp could be determined. The model gives as result the evapotranspiration and the yield. With these two parameters the green water footprint is calculated for the top-ten industrial hemp producing countries in the world. Within the top-ten industrial hemp producing countries the green water footprint varies between 415 m^3/ton (the Netherlands) and 5,300 m^3/ton (Turkey). The global green water footprint is the weighted average of the green water footprint of each of the top-ten industrial hemp producing countries. This results in a global green water footprint of 1,925 m^3/ton.

The blue water footprint is the related to the amount of water that is needed for irrigation of the crop. Based on scientific studies is concluded that industrial hemp can grow without any irrigation and that if the industrial hemp is irrigation that not increased the production of biomass and the yield. So there is no global blue water footprint of industrial hemp: WF_{blue} = 0 m^3/ton.

Use of fertilizers and herbicides result in the grey water footprint. The amount of water that is needed to compensate the amount of fertilizers and herbicides that is used to optimize the yield of the crop. In the case of industrial hemp there are no herbicides needed to increase yield. Only nitrogen (fertilizer) is globally used to improve production of industrial hemp. Based on scientific research is concluded that an amount of 150 kg/ha nitrogen is the best biomass production and yield optimization. For each country that is within the study the grey water footprint of industrial hemp is calculated. The results varies between 100 m^3/ton (the Netherlands) and 1,875 m^3/ton (USSR). The global grey water footprint of industrial hemp is the weighted average of the grey water footprints of the top-ten industrial hemp producing countries; WF_{grey} = 645 m^3/ton.

The total global water footprint of industrial hemp is the sum of the green, blue and grey water footprint of industrial hemp. So the total global water footprint for production of industrial hemp is 2,570 m^3/ton. Figure 16 shows the water footprints of industrial hemp for the top-ten industrial hemp producing countries and the total global water footprint.

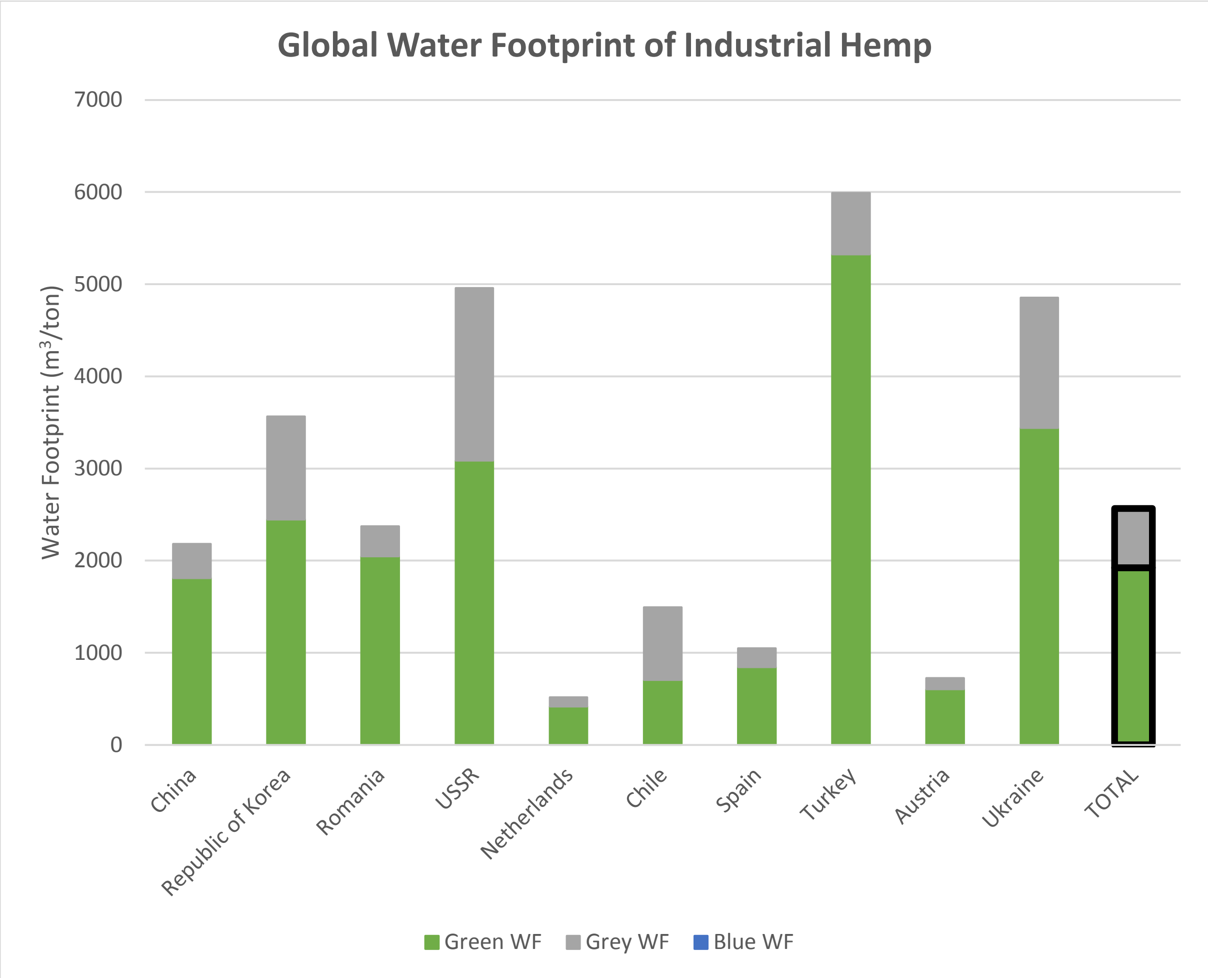

FIGURE 16. THE GREEN, BLUE AND GREY WATER FOOTPRINTS OF INDUSTRIAL HEMP IN THE TOP-TEN INDUSTRIAL HEMP PRODUCING COUNTRIES AND THE TOTAL GLOBAL WATER FOOTPRINT OF INDUSTRIAL HEMP

6.2 Water footprint of process and industrial hemp textile

To get the derived crop products for the industrial hemp there are some processing steps required. To get industrial hemp textile the following steps are distinguished: harvesting – retting and decorticating – wet processing – finishing. The last two steps of these process haves a process water footprint; in total this is 158.5 m^3 per ton of industrial hemp textile.

The water footprint of industrial hemp textile is a combination of the water footprint of hemp growing, the water footprint of processing and the product and value fractions of the different derived crop products. The water footprint of production was determined as 2,570 m^3/ton. The waterfootprint of processing was determined as 158.5 m^3/ton of industrial hemp textile. The products fractions are based on observations about the amounts of produced products. Value fractions are related to the market prices of the different crop derived products of industrial hemp. With these four factors together the total global WF of industrial hemp textile are calculated. This WF is 2,819.9 m^3/ton.

6.3 Comparison between industrial hemp and cotton textile

Based on the comparison between industrial hemp and cotton textile the following conclusion are made:

- The water footprint of cotton textile is more than three times larger than the water footprint of industrial hemp textile
- Products of industrial hemp textile have many advantages over products of cotton textile: industrial hemp is four times softer, industrial hemp is three to eight times stronger, industrial hemp is much more durable, industrial hemp is flame retardant, industrial hemp is not affected by UV rays, industrial hemp is very breathable but also very moisture absorbent
- The production areas of cotton textile are for a greater part in water scarce regions in the world. Industrial hemp is mainly grown in parts of the world were a little or no water scarcity is, so production of industrial hemp is less stressful for the environment

6.4 Recommendations

Further research to implementation of industrial hemp in AquaCrop is recommended. Therefore a calibration of the parameters of industrial hemp crop in required. Also for the other crops that are implemented in AquaCrop this is done (Zhang, et al., 2013); (Farahani, et al., 2009).

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