The water footprint of organic and conventional dairy farms in the northern Netherlands

Abstract

Freshwater is a scarce resource. A large amount of freshwater is used in agriculture. This research aims to find if there is a difference in water footprint between organic and conventional dairy farms in the north of the Netherlands. A water footprint consists of green, blue, and grey water. Green water is precipitation, blue water is water from surface or groundwater, and grey water refers to the amount of pollutant in groundwater. 98% of the water footprint of dairy farms is the water used to produce animal feed. To find the difference in water footprint between dairy farms, a water footprint was calculated for 17 farms; 9 conventional and 8 organic. To calculate the water footprint, data from the Annual Nutrient Cycle Assessment was used for each farm. No significant difference was found in the total water footprint, but it was found that conventional farms have a higher blue and grey water footprint. This is due to organic farms feeding more roughages and conventional farms feeding more concentrates. Concentrates have a higher blue and grey water footprint than roughages. Green water is more susceptible to climate change than blue water. Organic farms have a lower grey water footprint and are therefore considered to be more sustainable.

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1. Introduction

The world population is expected to grow to 9.7 billion people by 2050 (United Nations, 2019). Population growth and economic growth will put pressure on the availability of freshwater (Ercin and Hoekstra, 2014). The global demand for freshwater is rising, but due to climate change, the supply is sinking (Vörösmarty et al., 2000). Globally, the primary user of water is the agricultural sector (Hoekstra et al., 2011). In the Netherlands, one of the main agricultural products is dairy. Research has been done regarding the ecological footprint of dairy and whether organic farming is a more sustainable option (Oudshoorn et al., 2011; Thomassen et al., 2008). These studies, however, have not taken water usage as a leading indicator of sustainability. Hoekstra developed the water footprint as an indicator for freshwater use and pollution among supply chains. The water footprint is relevant since freshwater is scarce, and some types of water are scarcer than others. In more recent years, studies have been conducted on the water footprint of dairy and other animal products (Hoekstra, 2012; Mekonnen and Hoekstra, 2012). They found that animal feed is the main contributor to the water footprint of animal products. But in these studies, organic farming has not been considered; they consider dairy farming on a national scale, therefore generalizing the different types of dairy farming. Palhares and Pezzopane (2015) conducted small-scale research comparing the water footprint of a conventional and an organic dairy farm in Brazil. According to their research, organic farming did not generate a smaller water footprint; the footprint depended on water availability and nutrition management. In recent years, there has not been much research done about dairy and water use, even though this is an important topic.

In the Netherlands in 2017, 2,7% of dairy farms were organic (Wagenberg et al., 2017). This is only a small amount of all farms in the Netherlands. Since organic farms are usually smaller than conventional farms, only 0.5% of the dairy produced is organic (Rosati and Aumaitre, 2004). Yet organic farming aims to be more sustainable than regular farming (Wagenberg et al., 2017).

Dairy farming is reliant on the climate. In dry years, such as 2018, the grass yield reduced by 20 to 30% compared to average years (Prins et al., 2018). This means that there was less feed available for the animals. One dry year can be balanced by the surplus in feed from previous years, but that will not be possible in the future if it is dry multiple years in a row.

By looking at both organic farms and conventional farms, a difference in water footprint between them can be investigated, and it can be considered if a shift to organic farming would be an option for more sustainable dairy farming in the future. The research aims to find the difference in water footprint since it is unknown if there is a difference in water footprint between organic and conventional farms.

The research is guided by the following research question: What is the difference in water footprint between conventional and organic dairy farms in the Northern Netherlands.

To answer this question, several sub-questions are used:

What are the main differences between organic and conventional dairy farms?

How to calculate the water footprint of dairy farms?

What is the main water use of dairy farming?

1.1. Structure of thesis

This thesis consists of 6 chapters. Chapter two further elaborates on water footprints and the theory behind different water use between organic and conventional farms. Chapter three explains the research methods. Chapter four consists of the results found in the research. Chapter five discusses the results and connects them to the literature of chapter two. Chapter six answers the research questions, and recommendations for future research are given.

2. Theoretical Framework

2.1. Water footprint

The water footprint is an indicator that can be used to convey water-use data of different products, in relation to consumption, instead of production (Chapagain et al., 2006). This tool can be used on a national scale (Chapagain et al., 2006) or on scales as small as one farm (Palhares and Pezzopane, 2015). The water footprint is the volume of freshwater used to produce goods and services. This research focused on the water footprint of raw milk on the farms, not the rest of the production chain.

The water footprint distinguishes different types of water; green, blue, and grey/diluted. Green water is defined as water originating from precipitation (Chapagain et al., 2006; Palhares and Pezzopane, 2015). 87.5% of the water footprint of dairy is green water. Blue water is defined as irrigated water (Chapagain et al., 2006; Rost et al., 2008) or consumptive water use, including irrigation, drinking water for animals, and water in the product itself (Palhares and Pezzopane, 2015). Grey water or dilution water is the volume of water required to dilute polluters in the water to an acceptable level (Chapagain et al., 2006; Palhares and Pezzopane, 2015).

The water footprint can consist of multiple factors, adding up to the total water footprint. These factors can be direct or indirect. In dairy production, the water a cow drinks is a direct factor for the milk produced by the cow, but the water used to grow animal feed is an example of an indirect water footprint (Hoekstra et al., 2011).

Blue water is scarcer than green water. Blue water resources are surface water and groundwater, which are limited. Blue water is considered unsustainable when the depletion exceeds the renewable blue water. If the blue water sources are not receiving new water, ground water levels will be depleted (Mekonnen and Hoekstra, 2020). Ground water depletion mainly takes place in areas with crop irrigation (Dalin et al., 2017). Green water, which consists of rainfall, can also scarce, but when there is not enough precipitation, the shortage has to be resolved by adding blue water (Hoekstra et al., 2011). It is argued that only 56% of green water used is sustainable. The rest is depleting green water recourses, meaning more rainwater is needed than precipitation falling (Schyns et al., 2019). Grey water is relevant because it considers pollution. A farm can use little water but still pollute its groundwater. Since freshwater is a scarce resource, a low water footprint is preferable.

2.2. Differences in farming

Conventional farming focuses on increasing yields, using technology, breeding more productive livestock, modernizing feeding techniques, and using medicine and pesticides (Wagenberg et al., 2017). Organic farming, on the other hand, focuses on four principles: health, ecology, fairness, and care (IFOAM, 2005). Health and ecology mostly tie in with the water footprint concept, being the more technical principles. A life cycle assessment study found that organic farming is not necessarily more sustainable than conventional farming because emissions per litre milk yield can be higher due to the extensiveness of organic farming (Thomassen et al., 2008). Conventional farming allows for pesticides and artificial fertilizer, which are prohibited in organic farming (IFOAM, 2005; Sivaranjani and Rakshit, 2019). This is influential for the grey water footprint of these types of farms (Hoekstra et al., 2011).

One of the principles of organic farming is that cows have to be able to graze outside whenever the weather allows it (Smolders and Plomp, 2012). Conventional farms can choose to have their cows graze and label their product accordingly or not to graze at all. This is an essential difference between organic and conventional farms.

2.3. The water footprint of dairy

Animal feed is the most significant contributor to the water footprint of animal products (Mekonnen and Hoekstra, 2010a). Globally, the average water footprint of milk is 1020 m^3/ton milk (Mekonnen and Hoekstra, 2012). In the Netherlands, this footprint is much lower, only 528 m^3/ton. One reason for this is that the Netherlands has a suitable climate for dairy farming, generally having high milk yields. 85% of the water footprint of dairy is green, 8% blue, and 7% grey.

2.3.1. Feed

According to Palhares and Pezzopane (2015), the water footprint of a farm consists of the following: animal feed, drinking water, irrigation, and manure and fertilization. It is indicated that the main contributor to the water footprint of dairy is animal feed. Hoekstra stated that up to 98% of the water footprint of animal products is based on feed (Hoekstra, 2012). The 'annual nutrient cycle assessment' (ANCA)(Aarts et al., 2015) indicates six different types of animal feed; fresh grass, grass products, silage maize, other roughages, concentrates, and milk products. Gerbens-Leenes et al. (2013) divide all animal feed into two groups: roughages and concentrates. They stated the global average water footprint of these two types of feed. The total water footprint of concentrates is 5.2 times higher than that of roughages. Green water is the most significant part of this footprint. The blue and grey water footprints of concentrates are respectively 43 and 61 times higher than those of roughages (Gerbens-Leenes et al., 2013). These differences can be accounted to the fact that most roughages are rainfed crops and concentrates are crops where more irrigation and fertilization are used (Hoekstra, 2012). This can influence the composition of the overall water footprint of a farm.

If a farm feeds their animals roughage only, the water footprint is expected to be lower than that of a farm feeding concentrates. Roughages have a lower water footprint per ton of product, but more tons need to be eaten to reach the same nutritional levels that are reached with a ton of concentrated feed (Rosati and Aumaitre, 2004).

A difference between organic farms and conventional farms is that organic farms tend to have more roughages in their rations than concentrates when compared to conventional farms. Zom and Smolders (2009) give several reasons for this. The first and most important reason is that the price of concentrates is higher than that of roughages. More roughages in the rations lower the milk yield, but since the price farms receive for organic milk is higher, this price-returns division might be worth it. The following reason is that organically produced concentrates are scarcer than non-organic variants. Some organic farms choose to keep their nutrient cycle closed within their farm or region, which means not importing any concentrates. A group of farms do not want the animal feed to compete with human food. This means they do not want any concentrates that include crops suitable for human consumption (think of soy and maize) and only feed their cattle by-products and crops unsuitable for human consumption. The last reason is that some farms are so extensive that they have an abundance of roughages, and feeding that to the animals is the only way to get rid of them. (Zom and Smolders, 2009)

Dairy farms rely on animal feed. In dry years the yields of grass and other crops are much lower than in average years (Prins et al., 2018). It is expected that there are more dry years to come because of climate change (Philip et al., 2020). Droughts first influence green water, because in dry seasons there is less precipitation and more evaporation. Farms that have a higher green water footprint are therefore more reliant on the climate and therefore more susceptible to climate change. Blue water is scarcer than green water and depletes ground water and other blue water sources. This means that a high blue water footprint is not preferable as well.

2.3.2. Fertilization

To fertilize the grassland (and the maize silage crops), farms distribute the manure of their cattle over the land. Additionally, conventional farms can also choose to use artificial fertilizer to increase the growth even more. Organic farms are not allowed to use artificial fertilizer. Fertilizers influence the grey water footprint since fertilizer can leach into the groundwater, polluting it. The main nutrient in fertilizers is nitrogen. According to Hoekstra and Chapagain (2008), 10% of nitrates added to the soil leach into the groundwater. The European allowed standard for nitrates in groundwater is 50 mg/L. (directive 2006/118/EC of the European Parliament and of the Council, 2006).

2.3.3. Blue water

One factor of the water footprint of farms is the animals drinking water which falls under blue water. It is difficult to measure how much a cow drinks since grazing cows can sometimes drink from streams or ditches, and sometimes the water supply originates from a well, where no measuring tool is used to say how much is used. According to Agrifirm, an animal feed company, a lactating cow drinks four times its milk production in water and 40 additional litres (Voorkom tekort aan drinkwater, 2020). For a cow producing 40 litres of milk, this would be 200 litres of water a day. According to Michigan State University (Thomas, 2011), a cow drinks 150 litres of water a day, and according to agricultural company Lely, a cow drinks 4 litres of water per kilogram of milk it produces (Drinking behaviour in dairy cows - Lely, n.d.). This is much water, but this would still only be around 1% of the total footprint of dairy if the previously mentioned 528L/kg is taken. The water intake of cows is expected to be the same for both organic and conventional farms.

2.4. Conceptual Model

Figure 1 gives a simplified visual view of the effects of feed on water footprint composition. Since animal feed production is responsible for up to 98% of the water footprint of animal products (Mekonnen and Hoekstra, 2010a), this is the focus of the conceptual model. According to Mekonnen and Hoekstra (2010), the footprint of grazing globally is entirely green. Organic farms have more hours of grazing than conventional farms (Wagenberg et al., 2017), suggesting a higher fraction of green water in the overall footprint and vice versa for conventional farms. Non-organic crops have a higher grey water footprint (Mamathashree et al., 2017). The use of non-organic feed will therefore lead to a higher grey water footprint in conventional farming. Conventional farms are expected to have a higher ratio of concentrates in their food rations and are expected to have a higher blue water footprint (Gerbens-Leenes et al., 2013). Since conventional farms are allowed to use pesticides and fertilizer (IFOAM, 2005), the grey water footprint is also higher than that of organic farms. Conventional farms are expected to pollute more than organic farms. Organic farms, which are expected to feed more roughages, have a higher green water footprint. This leads to the expectations of organic farms being more susceptible to climate change than conventional farms. Conventional farms, which are expected to feed more concentrates, have a higher fraction blue water, and deplete blue water sources more than organic farms.

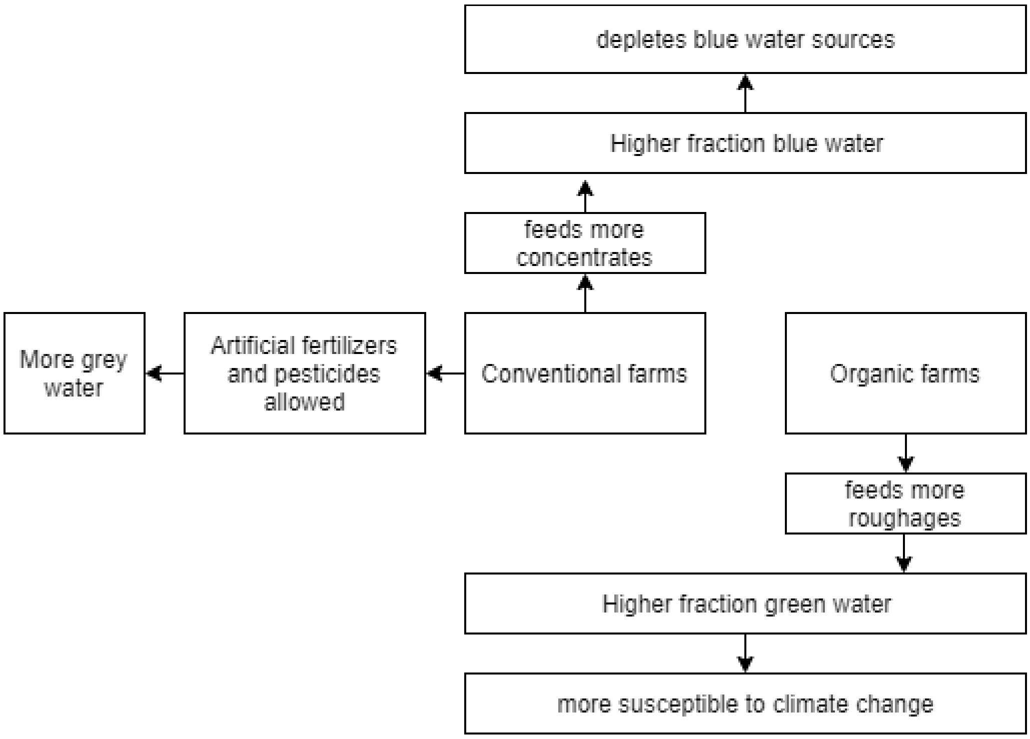
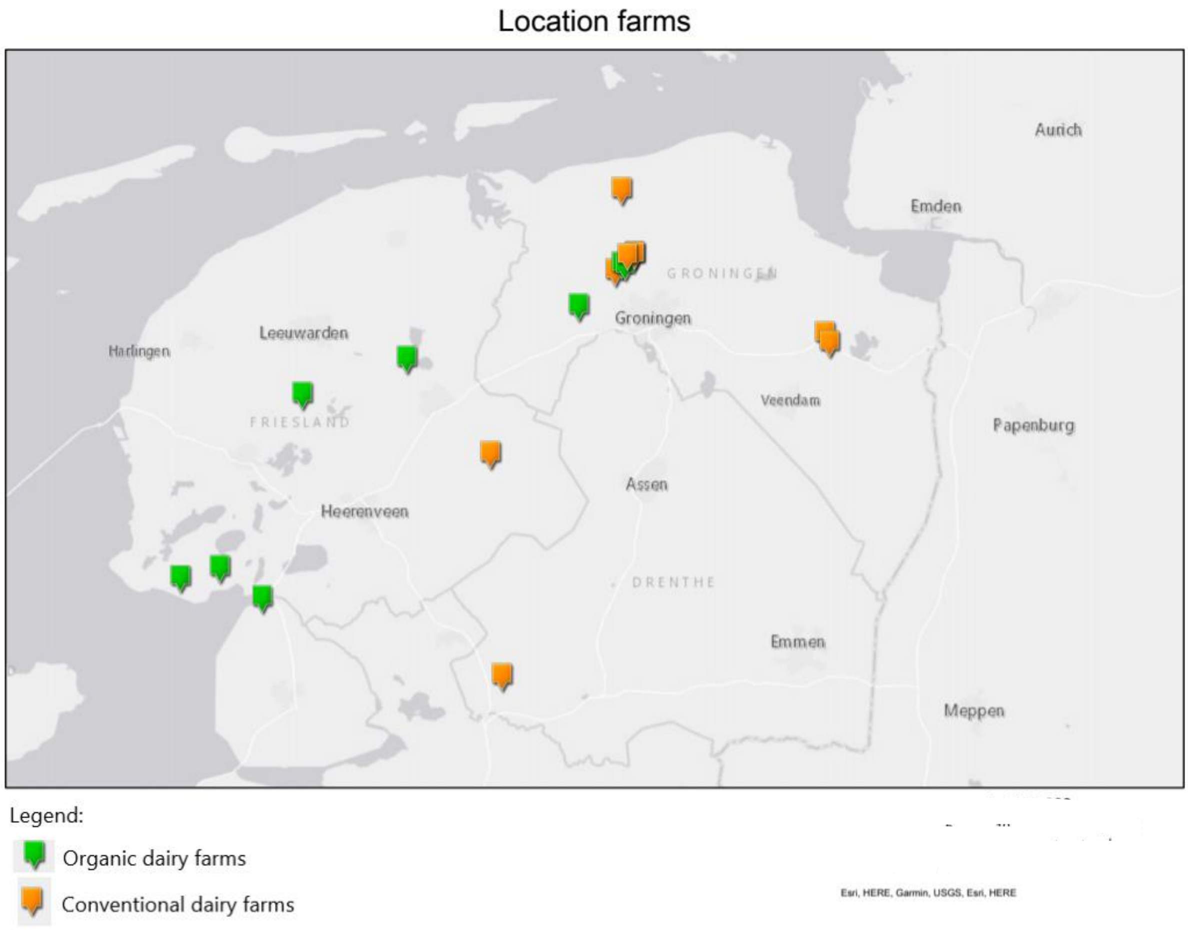


Figure 1: influence feed on types of water footprint

3. Methodology

To find the difference in water footprint between conventional and organic dairy farms, 17 dairy farms were analyzed; 9 conventional dairy farms and 8 organic dairy farms, all situated in the northern provinces of the Netherlands (Groningen, Drenthe, Friesland, Flevoland). The exact locations of the participating farms can be found in map 1. There is a cluster of farms in the middle of Groningen, here three organic farms and three conventional farms are situated. The choice to limit the study to this area was made to eliminate differences in precipitation and soils largely. These differences are present on a small scale as well, but that is not considered within the scope of the research. The participating farms/farmers were asked to share data from 2017, 2018, and 2019.



Map 1; location of farms.

3.1. Data collection

For the research, the participants were dairy farmers. They were asked to share data about their farms and their water use.

Participants were first contacted via social media, phone or e-mail, to ask whether they were interested in participating. If they were, they got an e-mail elaborating on the research and what data was needed of them. This data was the Annual Nutrient Cycle Assessment reports of 2017, 2018, and 2019. In addition to that, the amount of water used on the farm in each year (m^3) was asked, which they could take from their water bill. The location of their farm was asked to make sure they were in the northern Netherlands and whether their farm was organic or conventional. If after a week there was no response yet, a reminder was sent.

3.1.1. Sampling Bias

The way of sampling used is snowball sampling. Snowball sampling is asking participants to ask others they know who might want to join. The start of this snowball sampling was the personal network of the author. This method leads to a sampling bias, this being that participants will ask people they know who are interested in joining in a research, not farmers who are not. This leads to the sample possibly not being a representative sample of the population. This study is a small-scale study with 17 participants. The samples are 8 and 9 cases, which means a non-parametric test was used. Both samples are almost the same size, because if they were a different size, it is less reliable to compare.

3.1.2. Annual Nutrient Cycle Assessment (ANCA)

The Annual Nutrient Cycle Assessment (ANCA) is a tool developed by Wageningen University of Research (Aarts et al., 2015). It is meant to give farmers insight into the nutrient cycles of their farms. With this tool, a farmer can see if they are fertilizing effectively if they are feeding effectively, and how much CO2 they emit. Most farmers fill out this report every year. After filling in this tool, they get a report of all outcomes and can use it to optimize nutrient cycles on the farm. The reports contain data relevant to the study. While there is no focus on water in the nutrient cycle tool, most data needed to calculate a water footprint is present. From the nutrient cycle reports, the following figures were taken.

- ‘Farm portrait’, which included the amount of milk produced each year, the number of cows, and the size of agricultural land belonging to the farm;
- ‘Appendix 2A: Cattle results – rations’, which stated how much feed was taken into the livestock, and what kinds of feed (fresh grass, grass products, silage maize, other roughages, concentrates and milk products);
- ‘Appendix 4B: analysis manure streams’ stated how much manure was used as fertilizer and how much manure was produced in the meadows by the cows.
- For conventional farms, ‘Appendix 3B: Soil results – fertilizer’ was used, stated how much artificial fertilizer was spread out.

3.2. Ethical considerations

Due to Covid-19, all data was collected by either e-mail or phone call, so both the participant and the researcher were not at risk. The data farmers shared is private data of their farms, and this data must be handled discreetly. Data were processed anonymously; farms were given a code (B1-B8 for organic (‘biologisch’ in Dutch) farms and C1-C9 for conventional farms). The raw data will be deleted one year after the research, and it will be kept on a USB drive, where the researcher will be the only one who can access it. The collected data will solely be used in the research, and not for publication. The data will not be shared with any third parties.

Before sharing their data, participants were informed on what the data was used for, and it was pointed out that all personal data will be anonymized. Furthermore, participants will be asked for their consent. This consent can be withdrawn at any point in the research, which would lead to the data immediately being deleted.

All communication was done in Dutch to accommodate the participants. The participants will be sent the summary translated into Dutch, and if they are interested, the entire thesis.

3.3. Calculating the water footprint

All water footprints were calculated per kilogram of milk to even out the differences between large and small farms and make a fair comparison. Averages of 3 years were taken to even out things like drought, a bad year, or missing data. For some farms, some data was missing in specific years; for these farms, only the complete years were used in the calculations.

3.3.1. The footprint of the feed

To calculate the water footprint of the feed, the amount and type of food eaten by the animals on the farms were taken from the nutrient cycle report.

Table 1: water footprint of feed (Gerbens-Leenens et. Al, 2013)

L/kg	green	blue	grey
concentrates	849	78	122
roughages	199	1,8	2

In table 1, the water footprint of the two types of feed can be found, and these figures are used in the calculation. The numbers are M3/ton of feed, which can be read as l/kg as well. This table was taken from Gerbens-Leenens et. al (2013). By taking the amount of feed in kilograms and multiplying it with the amount of water needed to grow the type of feed, the water footprint of the type of feed is found. Then add the types of feed together and divide the total number by the kilograms of milk produced and the water footprint of feed per kilogram of milk is found.

These formulae were used:

$$GWF_{feed}= (M_{roughages}*GWF_{roughages} + M_{concentrates} * GWF_{concentrates})/P$$

$$BWF_{feed}= (M_{roughages}*BWF_{roughages} + M_{concentrates} * BWF_{concentrates})/P$$

$$DWF_{feed}= (M_{roughages}*DWF_{roughages} + M_{concentrates} * DWF_{concentrates})/P$$

GWF: green WF; BWF: blue WF, DWF: dilution/grey WF

M: amount of certain feed in kilograms

$WF_{roughages/concentrates}$: the water footprints of roughages or concentrates

P: produced milk in kilograms

3.3.2. The footprint of fertilizers

On both conventional and organic farms, manure is used to fertilize the soil to grow grass or other crops. On conventional farms, artificial fertilizers are allowed. To calculate the grey water footprint, the amount of fertilizer leached into the groundwater was used. This is 10% for Nitrates (Chapagain and Hoekstra (2008). The allowed for nitrates is 50mg/L (directive 2006/118/EC of the European Parliament and of the Council, 2006). The amount of N in the used fertilizers was taken from the ANCA report. In the case of multiple types of fertilizers (both manure and artificial fertilizer), it was added together. By dividing the amount of leached polluter by the environmental standard per liter, you get the number of liters needed to dilute the polluter to that allowed standard.

Formula:

$$DWF_{fertilizerN}=(N_{fertilizer}*L)/ES)/P$$

N: nitrates from fertilizer in kg

L: fraction of fertilizer leaching into the groundwater

ES: environmental standard in liters.

3.3.3. Blue water

Participants were asked to share how much water was used each year. This was divided by the kilograms of produced milk. This blue water is used for drinking water for the cows and cleaning the farm.

$$BWF= W/P$$

W: water used on the farm

3.3.4. The total water footprint

When the individual parts of the water footprint were calculated, they were added together. The blue water used on the farm was added to the blue water of the feed, and the grey water of the nitrates was added to the grey water of the feed. This resulted in the total green, blue, and grey water footprints. These were then added together to create the total water footprint per kilogram of milk.

3.3.5. Calculations

The water footprint was calculated for each farm individually, using the formulae mentioned above. Not every respondent had data available for every year. An average was taken of the years available. The formulae mentioned are relatively simple calculations that were done in Excel. This was then added together. The water footprints were imported into SPSS. Each farm's total or absolute water footprint was compared using a Mann-Whitney test, to test whether there is a difference between water footprints of conventional and organic dairy farming. The fractions of green, blue and grey water to the total water footprint, or the relative water footprints, were also compared using a Mann-Whitney test.

4. Results

The simplified version of the water footprint was calculated for all 17 farms individually. This water footprint is the blue water used on the farm, the grey water from nitrates in fertilizer, and the water footprint of animal feed. The results of the farms individually can be seen in figure 2. The average results can be seen in figure 2 and table 2. On average, the water footprint of the 8 organic farms was 392,37 litres of water per kilogram of milk produced. For the 9 conventional farms, this was 414,25 litres of water per kilogram milk produced. As can be seen in figure 2 the largest part of the water footprint is green water.

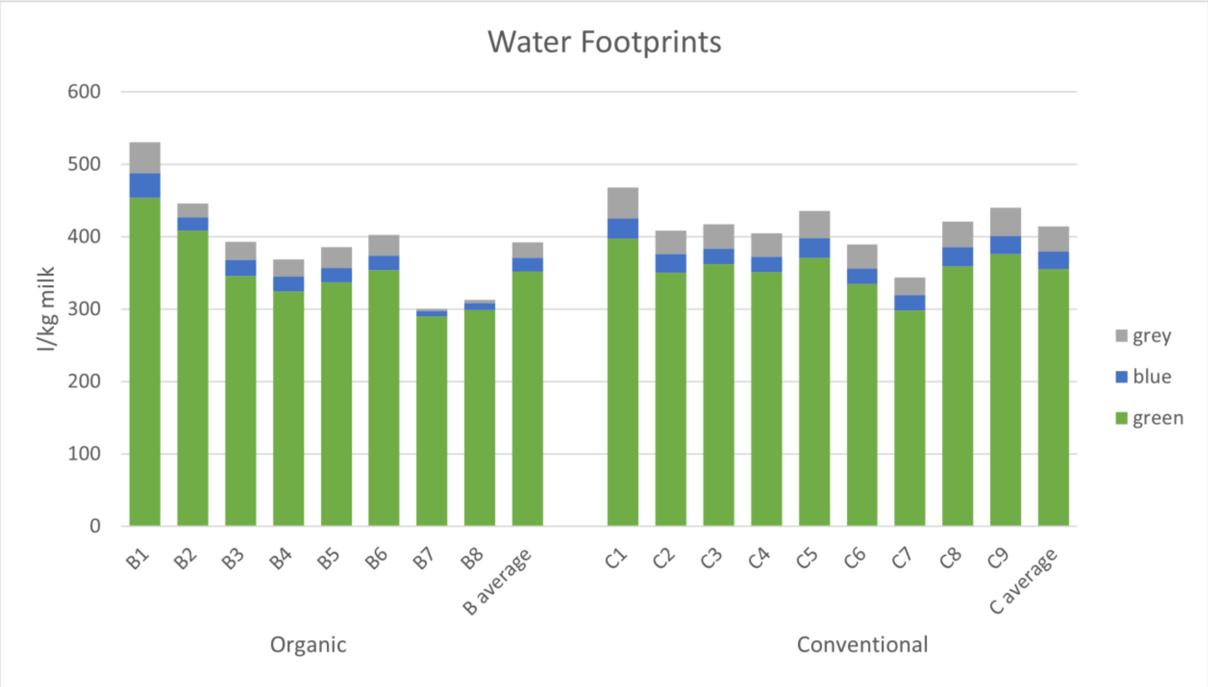


Figure 2: Water footprints of individual farms

The water footprints of the individual farms differentiate. Especially the organic farms' water footprint can be very different among farms.

Table 2: calculated water footprints

l/kg milk	total	green	blue	grey	%feed
Organic	392,37	351,64	18,89	21,84	
percentage of total		90,11	4,65	5,25	98,82
Conventional	414,25	355,49	24,24	34,52	
percentage of total		85,86	5,85	8,30	99,51

Of the total water footprints, 90% was green water for organic farms, and 86% was green water for conventional farms. The fraction of grey water was 5,2% for organic farms and 8,3% for conventional farms. 98,8% of the calculated water footprint was due to the feed on organic farms, and 99,5% on conventional farms.

4.1. Absolute and relative water footprints

Table 3: SPSS outcome water footprint

	Mean rank organic	Mean rank conventional	Mann-Whitney	Z-score	Exact Sig (2*1-tailed)
Green	8,00	9,89	28,00	-,770	,481
Green%	12,88	5,56	5,00	-2,983	,002
Blue	6,00	11,67	12,00	-2,309	,021
Blue%	6,38	11,33	15,00	-2,021	,046
Grey	5,88	11,78	11,00	-2,406	,015
Grey%	4,75	12,78	2,00	-3,272	,000
Total	7,38	10,44	23,00	-1,251	,236
Average % feed	6,00	11,67	12,00	-2,309	,021

In table 3, the SPSS output of the performed Mann-Whitney test is depicted. The test was done for both the absolute water footprints, so the liters per kilograms milk, and for the percentages, the different type of footprints contribute to the total water footprint. The null hypothesis was that there is no difference in water footprint between organic and conventional farms. The Mann-Whitney test was done on the total water footprint and the green, blue, and grey water footprints.

The test resulted in that the water footprint for conventional farms is always expected to be higher than those of organic. This result is not significant for the green water footprint and the total water footprint. However, it is significant for the blue water footprint and the grey water footprint, with a p-value of 0,021 and 0,016, respectively. These p-values are below 0.05, which is in line with a 95% confidence interval.

For the green and the total water footprint, this means that the null hypothesis was accepted; there is no difference in the green and total water footprint between organic and conventional farms. For the blue and grey water footprint, this means that the null hypothesis is rejected; there is a difference in grey and blue water footprint between organic and conventional farms.

For the relative water footprints, all outcomes are below p=0.05, meaning all percentages differ significantly between organic and conventional farms. The percentage of green water of the total footprint is significantly higher for organic farms. The percentages of blue and grey water are significantly higher for conventional farms. The percentage of feed accounting for the total water footprint is significantly higher for conventional farms.

5. Discussion

5.1. Green water

There was no significant difference between the absolute green water footprint of conventional farms and that of organic farms. There was, however, a significant difference between the relative green water footprints. The fraction of green water in the organic farms' water footprint is significantly higher than that of conventional farms. This is due to the animal feed of the farms. Organic farms feed more roughages, which have a higher green water footprint than concentrates (Zom and Smolders, 2009). A higher green water footprint means that organic farms are more susceptible to climate change than conventional farms.

5.2. Blue water

The blue water footprint of dairy farms is both absolutely and relatively higher for conventional farms than for organic farms. The relative blue (and grey) water footprints being higher for conventional farms is logical; since the fraction of green water is lower, the other part must be higher. Therefore, the relative water footprint will not be further considered. The higher absolute blue water footprint for conventional farms is due to the animal feed. Conventional farms feed more concentrates which have a higher blue water footprint than roughages (Hoekstra, 2012; Zom and Smolders, 2009). Blue water is scarcer than green water (Hoekstra et al., 2011), but less susceptible to climate change. The conceptual model showed that a higher fraction blue water is caused by more concentrates in the rations fed to the animals. The results found are in line with this.

The calculated blue water print is not entirely complete. The figures calculated were based on the blue water of feed and the blue water used on the farm. The blue water used on the farm does not include all the drinking water of the cows. This is because some of the drinking water is not measured. For some farms, all water consumed by the cows is tap water, which would be included in this calculation. However, for other farms water may come from wells or ditches where it is not measured. This means that the actual blue water footprint of farms might be higher than calculated in the research. It also means that the fraction of what drinking water contributes to the total water footprint is still expected to be 1%, even though it is not in this version of the water footprint.

5.3. Grey water

The grey water footprint of conventional farms is statistically higher than the grey water footprint of organic farms. This is due to both the higher grey water footprint of concentrated feed (Gerbens-Leenes et al., 2013) and the use of artificial fertilizer that is allowed on conventional farms (IFOAM, 2005). Therefore, conventional farms pollute water more than organic farms, which aligns with the conceptual model.

For the research, only the nitrates in fertilizer were used to calculate the grey water footprint. However, other parts of manure and fertilizer, such as phosphates, also influence this. What also was not considered is pesticides and antibiotics. To have a more realistic grey water footprint, the water footprint for these would be calculated.

For this grey water footprint, both the grey water footprint of feed and that of manure and fertilizer are calculated. However, a part of the feed eaten by the cattle is grown on the farm itself, so that part of the grey water footprint overlaps.

5.4. Feed

According to Hoekstra (2012), 98% of the water footprint of dairy was due to animal feed. The simplified version of the water footprint calculated found 98.8% for organic farms and 99.5% for conventional farms. This percentage is slightly higher than predicted, but this is due to the water footprint in the research not being entirely complete. The drinking water for cows could be higher, shifting the percentage of water due to feed down. Regardless of the drinking water, animal feed remains the main contributor to the water footprint.

The water footprint of feed calculated is an over-simplification of reality. All types of feed were put into two categories: roughages and concentrates. To get a more realistic view, the water footprint of every individual feed would have to be calculated. The same water footprint for concentrates was used for both conventional and organic farms, even though organically produced feed is expected to have a lower grey water footprint since artificial fertilizer and pesticides are not allowed in the production of that. This would lead to an even lower grey water footprint for organic farms.

The water footprint of grazing is entirely green (Mekonnen and Hoekstra, 2010b), but Gerbens-Leenes et al. (2013) made no distinction between grazing and other roughages. Therefore, it was not possible to find if more grazing leads to a higher fraction of green water footprint.

While roughages have a lower footprint per ton of feed, more roughages need to be consumed compared to concentrated feed to get the same nutritional value (Rosati and Aumaitre, 2004). Consequently, the lower water footprint of roughages is canceled out by the larger amount needed.

5.5. Total water footprint

The total water footprint of organic and conventional dairy farms does not significantly differ. The calculated numbers, 392 l/kg for organic farms and 414 l/kg for conventional farms, are lower than the 528 l/kg taken from Mekonnen and Hoekstra (2010). This can be explained by the blue water footprint not being complete and the footprint only being based on the farm itself, not on the rest of the production chain. The green, blue, and grey water footprints were for organic farms, respectively, 90%, 5%, and 5%, and for conventional farms, 86%, 6%, and 8%. In the research of Mekonnen and Hoekstra (2010), this was 85%, 8%, and 7%. The differences between the expected values and the found values can be explained by the footprint not being entirely complete.

There is no significant difference in total water footprint between both types of farms. A low amount of water used in farms is preferable since freshwater, both blue and green, is scarce. Conventional farms and organic farms use a similar amount of water in total, and in that perspective, are similarly sustainable. The different types of water, green, blue and grey, are where the distinctions can be found.

The total water footprints also differentiate between the types of farms themselves, especially the organic farms' water footprint.

5.6. Implications

There is no difference in total water footprint between organic and conventional farms. Since organic farms have a higher green water footprint, they are more susceptible to climate change. Conventional farms have a higher grey water footprint, so they pollute more than organic farms. A shift to organic farming would not necessarily increase freshwater security in the future, since both organic and conventional dairy farms use a similar amount of water, and organic farms are more reliant on the climate. However, a focus on optimal feeding and reducing the grey water footprint would be beneficial. If the feeding is optimized, the highest possible milk yield for the lowest amount of water used can be reached. And by limiting artificial fertilizers and pesticides, pollution can be kept at a minimum.

6. Conclusion

To answer the research question 'What is the difference in water footprint between conventional and organic dairy farms in the Northern Netherlands?' the following sub-questions must be answered.

The first sub-question was 'What are the main differences between organic and conventional dairy farms?'. The main difference between organic and conventional farms that influences the water footprint is the animal feed. Organic farms have their cows graze more and feed more roughages, whereas conventional farms feed more concentrated feed to optimize milk production. Organic dairy farms operate according to the four principles of organic farming, health, ecology, fairness, and care (IFOAM, 2005).

The second sub-question was 'How to calculate the water footprint of dairy farms?' Palhares and Pezzopane (2015) calculated the water footprint of dairy farms by looking at the water footprint of animal feed, drinking water and irrigation, and manure and fertilization. A simplified version of this water footprint was made that included the footprint of animal feed, blue water used on the farm, and dilution water of nitrates in fertilizer. Simple formulae were made to calculate these water footprints.

The last sub-question was 'What is the main water use of dairy farming?'. 98% of the total water footprint of dairy is due to animal feed (Hoekstra, 2012). This means that the main water use of dairy farming is the feed consumed by the animals. Next to that, a lactating cow drinks between 100 and 200 litres of water a day (Voorkom tekort aan drinkwater, 2020; Thomas, 2011; Drinking behaviour in dairy cows - Lely, n.d). This is around 1% of the total water footprint of dairy farms.

The main research question 'What is the difference in water footprint between conventional and organic dairy farms in the Northern Netherlands?' can now be answered. There is no significant difference in the total water footprint of dairy farms; organic farms and conventional farms use a similar amount of water per kilogram of produced milk. What does differ is the fraction of green water in the total water footprint; this is significantly higher for organic farms. The absolute blue and grey water footprints are higher for conventional farms. All the differences can be explained by the fact that conventional farms feed more concentrated feed, which has a higher water footprint than roughages. Green water is considered to be more susceptible to climate change than blue water. Blue water is not preferable since it is scarce. Grey water is unsustainable since it deals with pollution. Organic farming can be considered to be more sustainable since it has a smaller grey water footprint.

6.1. Recommendations

More extensive research needs to be done to find a more accurate water footprint of dairy farms, which would include all parts of fertilization and pesticides. Also, the footprint of all individual types of feed would be included. The sample size would also have to be more significant in size to draw more thorough conclusions.

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