Impact of roughage-concentrate ratio on the water footprints of beef feedlots

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ABSTRACT
The aim of this study was to determine the water footprint of beef feedlots up to the farm gate and evaluate the impact of roughage-concentrate ratio on the green water footprint. The study purpose was to provide strategic insights about nutritional management and water used that have a positive impact reducing water demand and increasing water efficiency. A regional bottom-up approach of the beef feedlot production was applied and water footprint methodology was used as the primary method. We included green and blue volumetric water footprint. Sensitivity assessment was done to explore differences in agricultural performance. Total water footprint ranged from 1935 to 9673 m³ kg⁻¹ of meat. The results are demonstrating the variability in water footprint that can exist from farm to farm. Green water represented on average 84.5% and blue water 15.4% of the footprint value. The farms with larger amounts of concentrate in the diet had high footprint values and the differences in feed composition have a significant effect on the water footprint. The average water footprint of the current crop yield was 5814 L kg⁻¹ of meat. With a reduction of 25% in the current crop yields, it was 7,416 L kg⁻¹ of meat and with an increase of 25% in the current crop yields, 4677 L kg⁻¹ of meat. These results show that increasing agricultural productivity has positive impacts on reducing the water footprint. The results show that the water footprint values of feedlots are determined largely by the type of animal diet and by performance indicators of the animals. The roughage-concentrate ratio and type of roughage are the nutritional aspects that most significantly influence the footprint values. This study supports the recommendation that beef feedlots should place emphasis on maximizing the use of roughage, because this could decrease the pressure on fresh water resources.

1. Introduction

It is important for producers to recognize the growing concerns attributed to water-animal nexus and for researchers to propose assessments to evaluate this nexus and improve water balance on livestock supply chain and farms. With the increasing demand for animal products in the coming decades, balancing animal productivity with water use will require a concerted effort among producers, scientists, agroindustries, and consumers to reduce the risks associated with animal water demand and scarcity. Numerous management and resource factors determine the environmental outcome on farms, and the impact of any change needs to be determined by taking into account the whole farm system.

There is increasing recognition of the tension between livestock production and water use, hence understanding the distribution and demands for freshwater in livestock production are of particular importance (Busscher, 2012; Ridoutt et al., 2014). To contribute to better insight into the demand for freshwater in a specific region and to improve the performance of individual farms, there is a need for water consumption studies to include detailed farm-level data regarding climate, agricultural practices, and utilization of feed (Jeswani and Azapagic, 2011; Krauß et al., 2015b; Ridoutt and Huang, 2012). Strzepek and Boehlert (2010) water scarcity will become a major limiting factor to food security due to possible inter-linkage and competition between the water and the food supply system. Sultana et al. (2015) to problems of water scarcity and food security, there is a need for research to develop appropriate strategies that optimize water use efficiency and increase livestock production without off-setting water resources. Winchester and Morris (1956), considering areas of limited water supply, quantitative information on water requirement of farm animals is comparable in importance to information on the animals’ other nutrient requirements. Sultana (2013) suggested that in terms of water use efficiency goals, benchmarking with other farms can be useful so that the individual farmer can see what others are able to achieve and can strive towards the best practice.

The world has over 1.3 billion cattle — about one for every five
people on the planet (FAOSTAT, 2015). Within the livestock sector, beef emerges as the commodity receiving most attention for its environmental impacts. Rabobank (2016) as countries continue to develop, greater incomes will be achieved, increasing food consumption and putting additional pressure on agriculture producers and water, especially in major producing regions. Gerber et al. (2015) this is due to the evident aggregated contribution that beef production makes to global environmental issues such as climate change and water use. Beef production from feedlots is expanding throughout the world. Feedlots are well established in countries such as the US or Canada and rapidly growing in other regions, such as South America, Asia, and Africa, driven by an increasing demand for meat in urban areas. Feedlots make use of relatively abundant crop products and co-products. Vasconcelos et al. (2007) feedlot operations are nevertheless associated with relatively high impacts on water resources and air quality, mostly due to the geographical concentration of production units. Tilman et al. (2002) stated that feedlots are generally sourced from industrial crop production, and thus contribute to environmental issues such as eutrophication, water depletion, and emission of pesticides into the environment.

Brazil is already the world’s second largest beef producer and exporter. The Brazilian beef industry is on the verge of a transformation towards rapid intensification (Rabobank, 2014). The beef feedlot industry has grown substantially in the last decade as the external market demand for fed cattle has increased. Brazilian cattle are fed in feedlots mostly during the dry season when pasture availability is decreased. In 2014, approximately 36 million cattle were slaughtered, which includes cattle on grass and in feedlots (IBGE, 2014). Approximately 10% of the cattle slaughtered in Brazil were finished in feedlots in 2014. Cederberg et al. (2009), today, a minor fraction of the Brazilian beef is produced in feedlot systems, but this production will most probably increase in the future. For upcoming studies, it is essential that resource use from complementary feed production is also included.

Most significantly, cow and calf producers draw on narratives of balance between economic and environmental concerns, focus on environmental benefits, emphasize good management principles, and fragment their understanding of the beef industry to maintain dis-This study considers the core processes of feedlot production and water footprint calculation is more challenging.

The water footprint approach provides information about water consumed and the impact of the product in the quantity and quality of water. Several approaches exist for assessing water footprint, and one of them is the Water Footprint Network method (Hoekstra et al., 2011). The water footprint concept was introduced as an indicator of freshwater appropriation, with the aim to quantify and map indirect water use and show the relevance of involving consumers and producers along supply chains in water resource management (Hoekstra et al., 2011). The evaluation of freshwater use is possible by assembling methods in a comprehensive methodology to adequately characterize each use. The current state of the art can already provide a preliminary understanding of water uses and associated impacts (Kounina et al., 2013). Manzardo et al. (2014) underlined the importance of applying water footprint accounting to minimize local effects on water resources, such as water stress and availability.

Mekonnen and Hoekstra (2012) estimated that beef cattle were responsible for 33% of the global water footprint of animal production and almost 10% of the global water footprint of total agricultural production. Water footprint of beef cattle in Brazil was based on global averages. No Brazilian case study was considered in the assessment, and this raises doubts whether regional- or country-specific case study footprints will be the same as the global averages. The global averages show very small variations, from 15,415–15,497 L/kg of beef, including green, blue, and grey water estimates (Ran et al., 2016). In contrast, the study by Mekonnen and Hoekstra (2012) presents relatively large variations between regions and production systems. Grazing systems, for example, have a range of 16,353–26,155 L/kg of beef, mixed systems of 11,744–16,869 L/kg of beef, and industrial systems of 3856–13,089 L/kg of beef.

The aim of this study was to determine the water footprint of beef feedlot up to the farm gate and evaluate the impact of roughage-concentrate ratio on the green water footprint. The study provides strategic insights about nutritional management and water used. This study presents the first water footprint assessment of Brazilian beef feedlot using farm-specific data, which does not currently exist in the scientific literature.

2. Material and methods

A regional (state of Sao Paulo, Brazil), bottom-up approach of the beef feedlot production was applied in the analysis and water footprint methodology was used as the primary method. Beef cattle feedlot is one of the production systems used in Sao Paulo, within which productive functions follow the general patterns of feedlots throughout Brazil. Bos indicus cattle is a common practice in Brazilian feedlots. Concentrate feed provided on each farm consisted of corn and soya meal; roughages are corn silage, sugar cane, and its bagasse.

2.1. Systems data and reference unit

Data used in this paper consists of both primary and secondary data. The study considered the core process of the feedlot (fattening stage where the animals are brought to the age of slaughtering) and the upstream processes: cultivation and animal feed (formulation A, formulation B, formulation C, and so on). Production of farm buildings, machinery, medicines, and pesticides were excluded.

The reporting period was one production cycle (from 80 to 110 days, average 90 days) based upon farm enterprise budgets. The underlying typical farm datasets were derived from Costa Junior et al. (2013). This research analysis was based on 17 farms (Table 1). Productive characteristics of each feedlot were based on process data from site visits and dialogues with property managers.

The reference unit was kg of fresh meat (meat with fat without bones and offal). The live weight of the animal was converted to carcass beef by multiplying live weight by 54.5%. This value was multiplied by
The potential crop evapotranspiration was calculated based on the crop coefficient method (Kc).

The crop evapotranspiration requirement (ETp, mm/period of growth) was calculated using the crop coefficient (Kc) for the respective growth period and reference crop evaporation (ETo) summed over the period from sowing to harvest (Allen et al., 1998). The crop coefficient is crop-specific and varies over time, depending on the growth stages of the crop (initial, crop development, mid-season, and late season). The sowing date, length of the growing period, and Kc values of a desired crop were also noted. Evapotranspiration for each feed consumed at each farm was calculated based on climatic data collected from the nearest and most representative meteorological station (CIAGRÜ, 2017). Land use for the production of grains, silage, and sugar cane was calculated based on total animal feed intake, considering a feed intake of 10.1 kg dry matter (DM) head⁻¹ day⁻¹ (Millen et al., 2009), one feedlot production cycle per year, and the crop yield.

Soybean crop produces two products, meal and oil. Meal is the form that cattle feed on. Technical conversion factors for agricultural commodities (FAO, Food and Agriculture Organization of the United Nations, 2013) were used to calculate the water quantity from evapotranspiration that is used to yield meal. Considering the Brazilian case, each grain produces 77% as meal and 23% as oil.

Blue water footprint refers to “blue water consumption” or “net water withdrawal” and is equal to the volume of fresh surface water and groundwater that is withdrawn and not returned because the water evaporated or was incorporated into a product (Mekonnen and Hoekstra, 2014). In this study, the blue water calculation comprises consumptive water use through animal drinking, water to feed mixing, and water in the meat. The equation for blue water is expressed as:

\[
BW = (\text{Wani-drinking}) + (\text{Wfeed}) + (\text{Wprod})
\]

where BW is blue water (m³ tonne⁻¹), Wani–drinking is consumption of (drinking) water by animals (m³ tonne⁻¹), Wfeed is consumption of water for feed mixing (m³ tonne⁻¹), and Wprod is the percentage of water in 1 tonne of meat.

Drinking water intake was calculated from the dry matter intake (kg day⁻¹), salt intake (kg day⁻¹), precipitation (cm day⁻¹), and maximum ambient temperature according to Hicks et al. (1988).

The water consumed for feed mixing is assumed to be 50% of total concentrate dry matter intake (DMI) (0.5 L kg⁻¹ DMI) according to Mekonnen and Hoekstra (2011). Water consumed to produce feed additives was not considered.

The grey component of WF, defined as the amount of water needed to dilute all the sources of pollution to restore a standard environmental condition, was not included in this study. Its estimation is quite
complex, mainly when the kind of pollution is diffuse, and could result in misleading water footprint results due to the great variability of runoff conditions that exist in each feedlot (i.e. different soils and nutrient concentration in the manure lead to completely different WF volume estimation).

### 2.3. Sensitivity assessment

Sensitivity assessment was done to explore differences in agricultural performance of maize silage, sugar cane and sugar cane bagasse, corn, and soya production per hectare. We used three scenarios which were applied to each feed ingredient in order to determine variation of the results: (1) actual crop yields; (2) reduction of 25% in the actual crop yields; and (3) increase of 25% in the actual crop yields. Table 2 shows the agricultural scenarios to each local.

### 3. Results and discussion

Table 3 presents water use by roughage and concentrate, volumetric and percentage of green water footprint, volumetric and percentage of blue water footprint, and the sum of blue water footprint and green water footprint.

<table>
<thead>
<tr>
<th>Farm Roughage (tonne ha⁻¹)</th>
<th>Maize silage actual Yield</th>
<th>Sugar cane Actual Yield</th>
<th>Concentrate (tonne ha⁻¹)</th>
<th>Maize actual Yield</th>
<th>Sugar cane +25%</th>
<th>Sugar cane −25%</th>
<th>Blue plus Green (L kg⁻¹)</th>
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<tbody>
<tr>
<td>Farm Roughage (tonne ha⁻¹)</td>
<td>Maize silage +25%</td>
<td>Maize silage −25%</td>
<td>Maize silage −25%</td>
<td>Soya actual yield</td>
<td>Soya +25%</td>
<td>Soya −25%</td>
<td>Maize actual yield</td>
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<td>47.7</td>
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<td>48.1</td>
<td>28.9</td>
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<td>502.1</td>
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<td>3 70.7</td>
<td>94.3</td>
<td>56.6</td>
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<td>1063.5</td>
<td>638.8</td>
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<td>4.5</td>
<td>2.7</td>
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<td>17 0.8</td>
<td>1.0</td>
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The sum of water footprints ranged from 1934 m³ kg⁻¹ to 9672 m³ kg⁻¹ of meat. The results are demonstrating the variability in water footprint that can exist from farm to farm when we calculate with farm-specific data that enabled this variation be captured. Green water represented on average 84.5% and blue water 15.4% of the footprint value. Hydro-efficiency in livestock depends on agriculture, because the highest water demand to produce meat is found in feed production. The larger percentage of green water confirms the importance of rainfall, which endorses why Brazilian agriculture and livestock have a competitive factor compared to other countries. Owusu-Sekyere et al. (2016) since green water is the largest contributor to the total water footprint for feed production for lactating cows, particular attention should be given to feeds such as maize meal, high protein concentrate feeds, and soybean, which have high green water footprints in order to minimize green water consumption. The farms with larger amounts of concentrate in the diet had high footprint values. When the concentrate represented 90% of the diet, footprints ranged from 6685 to 9673 m³ kg⁻¹ of meat. The inclusion of 80% represented a footprint variation from 4628 to 5236 m³ kg⁻¹ of meat. Farms 4 and 5 used the same roughage (sugar cane bagasse) and presented the same daily weight gain (1.5 kg day⁻¹), initial and final weights of the animals, and confinement period (90 days). However,
farm 4 used 80% of concentrate in the diet and farm 5 used 90%. The water footprint of farm 4 was 4628 m$^3$ kg$^{-1}$; farm 5 had a footprint of 7103 m$^3$ kg$^{-1}$; a difference of 2475 m$^3$ kg$^{-1}$ of meat or 53.5% more water. The increase in the amount of concentrate in the diet shall result in higher water footprints, but it should be considered together with the growth performance of animals and farm managements. A major driver of water use is the efficiency of feed conversion into product, which is determined by potential animal productivity as well as feed availability and quality throughout the year. Herrero et al. (2013) feed quality and feed efficiency are the key drivers of productivity and water consumption variations between production systems.

Concentrate dry matter intake results in higher water consumption because water used for concentrates is five times larger than that used for roughages (Hoekstra, 2012). Concentrate feeds have the highest water use because they demand higher evapotranspiration, which is strongly dependent on the geographic position. Disaggregated crop water use indicates that concentrated water clearly dominates over roughage water irrespective of the roughage-concentrate ratio. In this study, concentrated water ranged from 80.8 to 99.9% of the green water footprint. Values of crop water use indicate that this factor, which is dependent on regional differences and the evapotranspiration condition, drive water use in beef production. Millen et al. (2009) argued that the greater concentration of roughage in finishing diets is likely more feasible in Brazilian feedlots than in the other countries because feedlot operations are generally smaller and the availability and decreased cost of roughage favors greater use. As the capacity of feedlots increases, especially in areas in which the cost of land and roughage are more expensive, greater concentrate diets will possibly become a more common management practice in Brazil.

The differences in feed composition have a significant effect on the water footprint. Results indicate that the type of roughage influences the footprint values. Farms that used sugar cane bagasse as roughage had the highest dietary concentrate percentages; the average inclusion was 70%. On farms that used sugar cane, this average was 60% and 48% with corn silage. This is an aspect that is related to the nutritional quality of roughage. While sugar cane has a content of crude protein and metabolizable energy of 2.76% dry matter and 2.16 Mcal kg$^{-1}$, respectively, its sub-product (bagasse) has 2.03% dry matter and 1.78 Mcal kg$^{-1}$. Corn silage has 7.24% of crude protein in the dry matter and 2.41 Mcal of metabolizable energy kg$^{-1}$. Because of the lower protein value of sugarcane, farmers have to add larger amounts of concentrate to meet the needs of the animals.

Farms that used bagasse in the ratio of 10% showed high water footprint values. The uses of by-products in animal nutrition are understood as a mitigation action that reduces the values of water as well as ecological or carbon footprints. With the use of a by-product, only part of the water consumed by the main product is allocated to the by-product. In this case, bagasse represents 30% of the volume of sugar cane. Brazil is a major producer of agricultural commodities and therefore has a high availability of by-products that can be used as feed in the feedlots. The advantage of using by-products as feed is economical, and we also have to show that these require less water to produce one tonne of feed and one kilogram of animal protein.

For the ratio of 10%, the advantage of by-product was not verified. When the ratio was 20% (farms 4 and 6), footprint values were lower even when compared with farms with inclusion of 60 to 70% of concentrate. On farms with a ratio of 10% of bagasse, the confinement period was 100 days. This period was 85 days for 20%. Farm 8 had the highest water footprint and used corn silage as roughage and a diet with 90% of concentrate. Farms with sugar cane as roughage and the same percentage of concentrate presented footprints ranging from 6685 to 7345 m$^3$ L$^{-1}$ of meat. On farm 8, animals were confined by 107 days, while on farms with sugar cane as roughage, this period was on average 95 days. The roughage-concentrate ratio determines the performance of the animals, which will influence the confinement time and the value of the footprint.

Farms 7 and 16 used the same roughage (sugar cane bagasse), obtained the same daily weight gain (1.6 kg day$^{-1}$), confinement period (100 days), and percentage of concentrate (90%), but different initial and final weights of the animals. On farm 7, the initial weight was 270 kg and the final weight 433 kg. On farm 16, initial weight was 380 kg and the final 540 kg. The water footprint of farm 7 was 7103 m$^3$ L$^{-1}$ of meat and of farm 16, it was 6685 m$^3$ L$^{-1}$ of meat, with a difference of 418 m$^3$ kg$^{-1}$ of meat. Although the aspects of the genetic, type of diet, and daily weight gain were the same, the higher initial weight on farm 16 determined a lower water footprint. Better herd management prior to the confinement period and hence the entrance of heavier animals had positive impacts on the value of the footprint, improving liters of water relative per kilogram of meat. The ideal initial animal weight to start the confinement was 330 kg.

However, not only herd management prior to confinement, but also the management during confinement had an impact on the footprint value. Farms 1 and 9 used corn silage as roughage and a concentrate inclusion of 30 and 35%, respectively. Despite the lower concentrate inclusion on farm 1, its footprint was 14% higher. In both farms, the confinement period was the same (90 days), but they had different daily weight gains, 1.3 kg day$^{-1}$ (farm 1) and 1.5 kg day$^{-1}$ (farm 9). This determined animals with an average final weight of 357 kg on farm 1. This relationship was also observed between farms 7, 15, and 16, with concentrate inclusion of 90% and farms 6 and 4 with inclusion of 80%. The average final weight was different between them. Farm 16 had the lower footprint and the heaviest animals. In this farm, the animals were slaughtered with an average weight of 540 kg; up to 480 kg is the average slaughter weight in Brazil. Farm 4 had ten more days of confinement that farm 6, but its footprint was lower. In both farms, the initial weights were the same, but in farm 4, the animals finished heavier. We know that older animals use nutrients less efficiently and have higher feed conversion. This fact was not reflected in the footprint values, but should be studied in depth in future studies. We should analyze the balance of nutrients and methane emissions together with water use in order to identify the trade-offs between the nexus water-nutrient-emission. In addition, studies that integrate the evaluation of water consumption with the herd and management aspects to identify and propose mitigation actions should be developed.

The results of green and blue waters will be present and discussed in a disaggregated way to facilitate our understanding of the impacts of each water in the footprint. Ridoutt and Pfister (2010) expanded the discussion about water use by livestock production and stated that it is important not only to quantify aggregated water use, but also assess disaggregated water. The aggregated water (i.e. the sum of green and blue water) in animal products is potentially misleading and confusing because its use fails to take into consideration disaggregated green and blue water use.

A growing number of authors highlight the importance of including green water, as its inclusion demonstrates how rain fed agricultural systems reduce the demand and impact of blue water consumption. De Fraiture et al. (2007) the use of green water resources should be seen from a competition perspective when analyzing the current trend for an increase in the global demand for animal-source foods. Berger and Pinkbeiner (2010) the consumption of green water can cause water deprivation for ecosystems and also may reduce the renewability of ground and surface water, representing a severe shortcoming. De Fraiture and Wichelns (2010) water consumed by crops fed to cattle each year was 1312 km$^3$, or about 18% of the total crop water consumption. An additional 840 km$^3$ (12%) are consumed by grazing livestock.

Green water footprint on the farms ranged from 1165 to 8899 m$^3$ kg$^{-1}$ of meat. The results show that local differences in evapotranspiration and yields provide insights in why footprints are small or large in specific regions. Differences in green water use depended on soil agronomic features (pH, nutrient and mineral soils content, and texture), protected or unprotected systems, and geogra-
phical and/or temporal location, which can deeply affect the yield and the economic return. Although climatic and soil factors are important in determining evapotranspiration from crop fields and yields, water footprint is largely determined by agricultural management rather than by the environment in which the crop is grown (Rockström et al.; Mekonnen and Hoekstra, 2011). Mueller et al. (2012) a large increase in crop yields, without an increase or even with a decrease in field evapotranspiration, is achievable for most crops across the different climate regions of the world through proper nutrient, water, and soil management.

Water originating from roughage represented on average 4.4% of green water volume and from concentrate, this value was 95.6%. Farms with the lowest concentrate inclusion had the lowest percentage of concentrate feeds in green water volume. On farm 14, this inclusion was 25% and represented 81% of green water. On farms with inclusion of 90%, it represented an average of 99.5% of green water volume.

The type of roughage impacts the percentage of it in the green water footprint and when this is corn silage, representativeness of roughage is greater in the green water. The water footprint of corn silage varied from 137 to 160 m\(^3\) tonne\(^{-1}\), that of sugar cane from 137 to 160 m\(^3\) tonne\(^{-1}\), and that of sugarcane bagasse from 38 to 48 m\(^3\) tonne\(^{-1}\). Scarpere et al. (2016) calculated average green water to sugar cane in the state Sao Paulo to be 145 m\(^3\) Mg\(^{-1}\). Mekonnen and Hoekstra (2014) calculated the average global green-blue water footprint for sugarcane of 197 m\(^3\) tonne\(^{-1}\). In a study by Mekonnen and Hoekstra (2011), the green water footprint in a rain fed system for sugarcane was 164 m\(^3\) tonne\(^{-1}\). This value is lower than those found by Scholten (2009), which, on average, quantified above 200 m\(^3\) tonne\(^{-1}\). Palhares and Pezzopone (2015) stated that to produce 1 tonne of corn silage in the central region of Sao Paulo, water usage was 131 m\(^3\). Feed ingredients have different water footprints, resulting in differences in the total green water footprint.

On farms 1 and 3, the inclusion of concentrated feed was 30% and roughages were corn silage and sugar cane bagasse, respectively; 12.7% of green water on farm 1 was originating from silage, while this value was 4.1% for farm 3. When the inclusion was 90% and the roughage was sugar cane bagasse, it represented 0.3% of green water. On farm 8, with the inclusion of 90% and corn silage as roughage, this accounted for 1% of green water. Farms 2, 13, and 17 had 60% of inclusion and roughages were sugar cane bagasse, corn silage, and sugar cane. Roughage on farm 2 accounted for 1.9% of the volume of green water, for 4.8% on farm 13, and for 1.3% on farm 17.

Roughages feeds are different in their water productivity. We defined water productivity as the crop yield (kg ha\(^{-1}\)) by the crop evapotranspiration (m\(^3\) ha\(^{-1}\)). The averaged water productivity of corn was 6.5 kg m\(^{-3}\) and for sugarcane, this value was 6.9 kg m\(^{-3}\). Dry matter production per hectare of sugar cane is on average twice as high as for corn silage. However, if we calculate the protein water efficiency (m\(^3\) tonne\(^{-1}\) of crude protein), the corn silage average was 5174 m\(^3\) tonne\(^{-1}\) of crude protein and sugar cane average was 5502 m\(^3\) tonne\(^{-1}\) of crude protein. Despite the higher water productivity of sugar cane, the water footprints of the farms that use this roughage were higher due to the lower nutritional value of this product.

Corn had an average water use of 65.7% of green water from concentrate and 63.3% of the total green water. Soybean represented 34.3% of green water from concentrate and 32.3% of the total green water. The use of these grains in feedlots is justified by their high nutritional values and the positive impact on indicators of animal performance. Since water scarcity is a major issue of concern and, given the fact that it is directly associated with production cost, producers should carefully evaluate the water footprint of the various feed crops and minimize or substitute the ones with high water footprints with crops with lower footprints in order to be sustainable in terms of water use. If feeds are produced in regions or basins with water scarcity (green and blue), water quality problems from diffuse pollution, and conflicts over water use; we should promote the replacement by other concentrated feeds or enhance the roughage ratio.

In this study, we considered that both roughages and concentrates were produced on the farms, but this may not be the reality of other feedlots. Often, the concentrate is produced in another region. Imports of grains mean the import water and are water dependent. Considering the 17 locations of the farms, the water footprint of corn ranged from 1118 to 2326 m\(^3\) tonne\(^{-1}\) and that of soybean from 1534 to 2718 m\(^3\) tonne\(^{-1}\). Higher evapotranspiration resulted in a higher water use. This shows that, depending on the region, the water footprint can change significantly. Grain yield also played an important role, i.e., a larger yield was obtained because greater productivity led to a lower water footprint. Feed production in areas with poorer natural production conditions, less qualified farmers, and low technological development will negatively impact water management in livestock chains. São Paulo is not a state with a considerably high grain productivity. Drastig et al. (2016) soy produced in the state of Sao Paulo had the lowest crop water productivity when compared with other Southeast and Center-West Brazilian States, most likely because soy is not a traditional crop in Sao Paulo and the production conditions are not ideal. Erçin et al. (2012), water consumption of soy products is highly influenced by the location from which production inputs are sourced and the production conditions. This is more relevant for the agricultural inputs, because they largely depend on the location and management practices of the farms producing soy.

If the farm is located in a region of low rainfall, which prevents the production of grains, importation is a strategy that will enable the production of beef cattle. The choice of roughage feed can reduce the concentrate imported and has a positive economic impact because concentrate has the highest nutritional cost. Another strategy is the use of by-products, preferably those available in the region. Some examples of by-products that have been used in feedlots are citrus pulp, cottonseed, and peanut hulls. By-products could have lower water footprints depending on their nutritional content and the performance of the heads, as demonstrated by the use of sugarcane bagasse, and are also associated with lower costs. Soybean, at present the most used protein feed ingredient, and potential alternatives will play an important role regarding this matter. There is considerable room for expansion and increased usage of rendered products such as animal-by-product meals (Nates et al.; Tacon et al., 2011). Drastig et al. (2016) soybean and corn are not the only feedstuffs that can be used to meet the protein and energy requirements of the animals, although they are the most traditionally used ones. It is becoming evident that studies on feed composition should take water consumption by feed ingredients into consideration in order to formulate water-efficient diets. Choices about roughage and by-products should also consider the nutritional values.

Currently, the Brazil’s Southeast and Central regions are experiencing a chronic water shortage due to extremely low rainfall records when compared to the historical average and water withdrawals increases (Scarpere et al., 2016). The state of Sao Paulo has a water scarcity index of 73% (total water use by state water availability) and has been classified as a state with high water stress (40% < WSI < 100%) (Da Silva et al., 2016). In this high-density region, the available land for crop expansion is quite expensive, with an average of R$15,380.00 (Brazilian currency converted at 0.33 USD = 1 BRL, 2015 average value) (AEI, Applied Economics Institute, 2015).

Fig. 1 shows the values of the green water footprint in accordance with the productivity of crops. The average water footprint of the current crop yield was 5814 L kg\(^{-1}\) of meat. With a reduction of 25% in the current crop yields, it was 7,416 L kg\(^{-1}\) of meat and with an increase of 25% in the current crop yields, 4677 L kg\(^{-1}\) of meat. These results show that increasing agricultural productivity has positive impacts on reducing the water footprint. In many cases, techniques for increasing water productivity, especially when it is low, require little or no additional water.

The variation of the water productivity between the soil groups has been caused by the differing yields. Variation between water produc-
tivity of the different fields on the commercial farm was as high as the variation between the soil groups (Krauß et al., 2015a). Water productivities in crop production will need to be increased by increasing yields and reducing non-productive evaporation (Brauman et al., 2013; Foley et al., 2011). An important part of a strategy to reduce the pressure on limited blue water resources will be to raise productivity in rain-fed agriculture (Rockström et al., 2009).

On average, the productivity increase meant a reduction of 19.4% of the footprint value with a minimum reduction of 5.1% and a maximum of 65%. Decreasing or increasing actual yield for grass and maize production per hectare by 10% decreased or increased consumptive water use by 52% (De Boer et al., 2013). On the other hand, the lower amount of tonnes of feed per hectare resulted in an average increase of 26.4% of the footprint value, with a maximum of 30.5%.

If all crops used by the 17 farms had a 25% increase in productivity, this would result in a reduction of 20% of the agricultural area required for the production of feeds. On the other hand, a 25% reduction in productivity would result in 33% more area for feed production. Low water productivity in precipitation-limited regions was raised to the 20th percentile; the total rain fed food production in Africa could be increased by >10% without exploiting additional cropland. Similar improvements in water productivity in irrigated cropland could reduce total water consumption by 8–15% in precipitation-limited regions of Africa, Asia, Europe, and South America (Brauman et al., 2013).

Increases in water efficiency in the production of animal protein will be only achieved considering agriculture. Therefore, an integrated approach is essential to improve water performance in livestock, as well as consideration of green water consumption. If green water is not considered, this could mean no interest in the use of agricultural practices that have positive impacts on improving water efficiency. These practices also mean other environmental benefits, such as soil and water quality conservation.

Our results show how diet formulations influence the water footprint values. They also indicate that improvements in water efficiency of animal products should consider the nutritional management of the farms in order to propose actions and policies that promote positive impacts. Feed formulations are often termed “standard” in the literature, but feed for a certain beef type may differ significantly from country to country or within countries, depending on the producer’s practice, feed ingredient availability, financial means of the farmers, and the farming system. Precision feeding is formulating the ration to meet the nutritional requirements of the animals, especially in terms of protein and phosphorus. It can reduce feed costs and improve feed efficiency and animal performance. In the plan, whole-farm nutrient imbalances, nutrient buildup, and feed efficiency can be addressed. Tacon et al. (2009) in the short term, efforts should focus on further improvements in feed formulation techniques and on formulating rations on the basis of individual digestible nutrient levels rather than on crude gross nutrient levels and at the same time, aim to minimize the environmental and ecosystem impact of feeds and feeding regimes (Tacon et al., 2011).

The low feed conversion efficiency may be attributed to errors in feeding management or genetic factors, such as breed, as well as climatic factors such as heat stress. Careful nutritional managements to improve nutrient availability and quality as well as breeding programs that aim at enhancing growth rates can improve feed conversion efficiency. Naturally, there will be differences among the terrestrial plant-based proteins and lipids with respect to their green, blue, and grey water footprint, which must have implications when different goals are to be reached, e.g., the reduction of the blue water footprint, reduction of pollution, or reduction of the overall water footprint. The choice depends on the goal and therefore, we do not strive to provide explicit recommendations regarding the choice of feed ingredients (Pahlow et al., 2015). The climatic condition in a region of production and the methods for assessing evapotranspiration explain a large part of the variation between studies, since evapotranspiration can vary hugely between different areas and climates across the world. The variation in livestock water productivity for beef can also be explained by differences in feed quality, digestibility, and feed conversion efficiency between production systems (Ran et al., 2016). Diet composition and quality also determine the magnitude of the water footprint of meat and milk production. Improved diets translate to better feed conversion and, eventually, to more efficient use of freshwater (Bosire et al., 2015).

If we take a water approach combined with the knowledge that we have about ruminal physiology and nutritional management, we could reduce the green, blue, and grey water footprints because the animal better take advantage of the available nutrients and therefore require smaller amounts of roughage and concentrates, resulting in lower water use and agricultural areas.

The blue water footprint ranged from 766 to 774 L kg\(^{-1}\), the average value for the 17 farms was 769 L kg\(^{-1}\) (Table 2). This footprint represented 15.5% of the footprints on average, with variations from 8.0 to 39.8%. Detected differences in farm size are important because they influence the water footprint use from a single farm and determine the presence of scale economies for abatement of water cost and production.

Among the uses considered in the calculation, water in the meat was the biggest, followed by drinking water. Meat water had a mean value of 97% of the blue footprint and drinking water a value of 2.3%. Water to feed mixing was lowest. Despite the large percentage of blue water in the form of meat, the consumption of drinking water should be considered and related to the water availability in the basin. For example, farm 5 confined 50,000 animals per cycle, which means a drinking water consumption of 178,066 m\(^3\). The sustainability analysis
of this value is fundamental to propose measures that have a positive impact on water efficiency. The direct effect of changing beef water consumption in one region will impact the water availability in that region and its watersheds, reducing the conflict between water users. It may have little or no effect on water use for beef meat in other places, because much of the beef produced in these regions is being sold to other parts of the country and to other countries in the form of virtual water. Pfister et al. (2009) blue water use can have an impact on human health and ecosystem quality or can result in the depletion of water resources. The impact of freshwater use on human health, ecosystem quality, or resource depletion, however, is site-specific. Oki and Kanae (2006) withdrawing > 50–80% of the annual water flow (the exact figure depends on local conditions) leads to water stress, as water is also required for environmental use and ecosystem services.

Unlike green water, consumption of blue water is more perceived by the farmer, so the proposition of actions that contribute to its more efficient use will have a greater chance of being internalized by farmers. Kessler et al. (2016) an environmental impact occurring elsewhere is not tangibly experienced by producers, not measured by producers, and not understood through local, embodied knowledge. The authors conclude that abstract and cumulative impacts from beef production were not easily observed by producers and were therefore not the focus of producers’ environmental efforts.

Water content in the meat is a type of water for which we have little capacity for intervention. This content is related to the physiology of animals. It is possible that genetic factors influence its content, but to date, there is no data in the scientific literature that proves this hypothesis. Researches evaluating how genetic factors influence the meat water content should be encouraged in order to generate knowledge that enable the proposition of actions to improve water efficiency. Such information will also be interesting for agribusinesses and consumers as it will provide them with choices that improve the environmental condition. Beede (2012) additional research could prove useful to better understand the relative quantitative importance of other factors, such as genetic factors or accelerated growth rates of modern genetics that may influence cattle water needs at different stages of the life cycle in different environments. Brew et al. (2011) reported that cattle from tropical adapted cattle breed types consumed less water than British or continentally influenced cattle.

For the drinking water calculation, we considered zootechnical and environmental aspects of each farm. It has been known for a long time that body weight is an important consideration regarding the water intake (Winchester and Morris, 1956). In the present farms, the average final body weight was 480 kg and ranged from 357 to 540 kg. The average consumption of water per animal per day was 37.8 L, representing an average of 3.78 L kg⁻¹, with variations from 3.5 to 3.9 L kg⁻¹ of dry matter intake. Water intake related to dry matter intake was reported to be about 4 L kg⁻¹ of dry matter intake in cattle (Kamphues, 2000). Feedlots presented an average of 18 L kg⁻¹ of meat, with variations from 15 to 22 L kg⁻¹ of meat.

The maximum temperature in the farms ranged from 25 to 31.3 °C and precipitation from 2.7 to 4.8 mm day⁻¹. The farms with the highest maximum temperatures showed the highest drinking water consumption per animal per day (39.6 L). On farms with the lowest temperatures, the consumption per animal per day was 34.9 L. Brugger (2007), in a study on dairy farms, observed a direct correlation between drinking water consumed and ambient air temperature. During hotter months, the drinking water use was higher.

It supports that bioclimatic needs of animals is a mitigation management to reduce blue water demand from feedlots. In this way, the outcome will be a more sustainable blue footprint. It also subsidizes managements that provide greater thermal comfort to the animals, showing the impact that these will have on water demand. These managements will also reduce the cost of water and enhance animal performance. Farm 5, which showed the highest maximum temperature, could implement practices and technologies to give more thermal comfort to the animals. If temperature is reduced by 2 °C, water consumption per animal per day would be 38.2, a difference of 1.4 L day⁻¹. Considering the production cycle, this would mean a water saving of 6378 m² day⁻¹ or 3.6%.

Nutritional aspects had their values set for all farms according to the scientific literature, because these kinds of data were not measured by each feedlot. We know that the dry matter intake and diet quality are determining factors in the quantity of water consumed by animals. We should encourage farmers to monitor this information to obtain more accurate calculations of water use. It will also show the relations between nutritional management and water efficiency. > 50% of the clients serviced by the 31 cattle feedlot nutritionists did not manage feed bunks to control the quantity of feed offered per pen (Millen et al., 2009). Hansen et al. (2007) noted that more feed efficient bulls drank less water per unit of body weight gain than less feed efficient bulls. Meyer et al. (2006) found an average voluntary daily water intake of 17.8 kg bull⁻¹, varying from 0 to 78.7 kg bull⁻¹ for fattening bulls of the German Holstein breed. A positive relation was found between water intake and dry matter content of roughage, dry matter intake, roughage part of the diet, maximum ambient temperature, as well as sodium intake. Hatendi et al. (1996) observed a higher water consumption as a result of an increased roughage content of the diet.

Dry matter intake measurements also have economic significance since nutrition represents the largest cost in the production cost of an animal. Thus, the calculation of water consumption with more accurate intake information will provide the proposition of water friendlier nutritional managements and the evaluation of the economic viability of these managements. It is important to show to farmers the relation between production aspects and water resources. This approach will facilitate implement conservative water practices because the costs could be shared throughout the production system. Robinson et al. (2016) the main relationship between water taxes and future was that farmers who believed that water should not be taxed were also concerned about possible future water restrictions. Therefore, dairy farmers are concerned about future water access, but do not want to be taxed as an inducement to use less water.

Blue water footprint calculations for animal products are essential to better understand the water and animal protein relations, facilitate compliance with environmental legislation by farmers, such as obtaining water use permits, help in integrated river basin policies, and reduce the cost of water for farmers and the society. Lovarelli et al. (2016) state that blue water is expensive to use, since it has a high opportunity cost with which, reducing its use, both production costs (e.g., energy for pumping, machines, and plants to buy and manage) and environmental impacts (due to energy, materials, plants, etc.) are reduced as well. According to Girard (2012), there is a lack of knowledge of the water requirements of animals. Obviously, being aware of this situation is the first step towards improving the efficiency of water use in the production of animal products.

Calculations of blue water use could also assist to reach the fulfillment of sustainable development goals proposed by the United Nations. We highlight two goals: ending hunger by achieving food security and improved nutrition as well as sustainable agriculture (ensuring sustainable food production systems and the implementation of resilient agricultural practices that increase productivity and production by 2030) and ensuring the availability and sustainable management of water and sanitation for all (substantially increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater by 2030) (United Nations, 2015).

Producing sufficient food to meet future needs will require water development and management strategies that promote improvements in food security while maintaining the productivity of our land and water resources and enhancing environmental amenities (Molden et al., 2009). The aim for improved natural resource use efficiency, defined as the amount of natural resources engaged per unit of product, is an objective of global relevance which applies to the most affluent areas of
the globe, where the sector is requested to minimize its environmental impact, and to emerging economies, where livestock production expands rapidly in a context of relatively weak environmental policies and often wastes natural resources (Gerber et al., 2014). High-income countries have a greater capacity to implement best available technology and best practices than less developed countries, but our results indicate that less developed and tropical countries can reduce water footprints of crops (Mekonnen and Hoekstra, 2014). It would be useful to make footprint evaluations considering the best available technology and practice (e.g., optimized nutrient management, crop rotation, crop residue management, reduction of non-beneficial evapotranspiration, and effective rainfall enhancement) (Lavarelli et al., 2016). Despite the extensive concerted effort by governments and researchers over many years, success in protecting the environment is still questioned on the basis of (a) the efficacy of the individual measures proposed, (b) the suitability of some methods for certain farm types, (c) the actual level of uptake of the related technology, and (d) the conflict and incompatibility of methods for differing objectives (Loyon et al., 2016).

Animal production is inevitably associated with water consumption and therefore, some degree of water depletion seems unavoidable. Various strategies are available or can be developed to minimize depletion and achieve water efficiency. For this, animal scientists should understand the relation between livestock and water and consider water management in their works. Experience indicates that the required water efficiency in livestock will not occur without substantial financial and social investments in water management, agricultural research, supporting extension services, and rural infrastructure. Technical assistance, capacity building, and the right incentives and policies are required to motivate farmers to increase water efficiency.

4. Conclusions

The results show that the water footprint values of feedlots are determined largely by the type of animal diet and by performance indicators of the animals. The roughage-concentrate ratio and type of roughage are the nutritional aspects that most significantly influence the footprint values. Roughages with less nutritional value demanded higher inclusion of concentrate in the feed. On the other hand, if the roughage is a by-product, it will have a lower green water footprint, which can be an advantage if the feed is produced in an area with water scarcity, as well as an economic advantage, because by-products have a lower cost than the raw material.

If the greater use of concentrate means higher daily weight gain and meat productivity, as well as a shorter confinement cycle, it has a positive impact on the reduction of the footprint value, but for this to be achieved, not only the nutritional management is important. The other production system management techniques also have to be appropriate, including the phase prior to confinement. The use of best management practices in the production system could contribute to high performance indicators of animals and, consequently, they can reduce the percentage of concentrate in the diet and confinement cycle. Animal nutrition is an important factor in determining the water efficiency of beef products, but if the other aspects of the production system are not handled in the best way, they will negatively impact nutritional performance. It is noteworthy that concentrate feeds are commodities and even in countries that produce them in large quantities and with high yields, their prices are determined by international markets, so the use of these feeds in large quantities can also mean an economic threat to the production system.

The results of this study support the recommendation that beef feedlots should place more emphasis on maximizing the use of roughage feeds, because this could decrease the pressure on fresh water resources. Tropical countries have higher roughage production capacities, and this advantage should be considered in improving the water efficiency of animal proteins.

The green and blue water consumed is a result of either feeding strategies or performance indicators. Currently, decision-making under these two factors is determined by economic aspects, but this reductionism in decision-making will not be accepted, depending on the water scarcity and the global demand for environmentally better production systems. Therefore, the water consumed by livestock production systems should be quantified and evaluated in a systemic way. We also need to put a greater focus on water management data collection at the farm level and on how to benchmark and deliver useful information back to farmers. Strategies need to be tailored to local conditions and the combination of managing and policies and technologies will be required to achieve significant improvements.

Factors of supply chains have to be disposable robust tools for water decision-making. The results of the studies can subsidize relevant meat supply chain stakeholders (retails, farm and trade associations, compound feed producers, consumers, government representatives, non-governmental organizations, public agencies, and independent parties) to analyze and make decisions regarding water consumption and efficiency in beef feedlots, ensuring water security to this production system and animal protein. This study evaluated one of the environmental aspect of beef produced in feedlots. Future studies should consider all relevant environmental aspects. In this way, we could identify the trade-offs of meat production and support the best decision by stakeholders.

Water use by Brazilian livestock has increased in recent decades because of an unprecedented expansion. This means that the water consumed by this industry needs to decrease even further to alleviate local and regional stress on catchments and water resources.

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