Water footprint of alfalfa hay production in Córdoba, Argentina*

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INTRODUCTION: In 2017, Argentina exported 58,848 t of alfalfa feed, for a value of nearly 19.8 million USD (UNcomtrade, 2018). Even though it only represents 0.7% of the world trade, it involves large amounts of virtual water in the product, which deserves the attention of the stakeholders of the alfalfa value chain, for a sustainable, efficient and equitable use of natural resources. In this sense, the water footprint is one of the family of environmental footprints that quantifies the amount of water consumed, evaporated and polluted. Worldwide, various activities consume or pollute water, but most of the water use occurs in agriculture (Hoekstra, Chapagain, Aldaya, & Mekonnen, 2011). Water consumption and pollution can be associated with specific activities, but until recently, there was little awareness to relate it to the structure of the global economy that supplies the various consumer goods and services. Hoekstra and Chapagain (2008) quantified the effects of consumption and trade on water resources use, by visualizing the hidden water in the products. Fresh water is a global resource, but due to the world trade, there is a spatial disconnection between the use of water resources and its consumers. For instance, this is the case of alfalfa hay exported from Argentina to the Middle East, i.e., production and final consumption are located in different places. Therefore, in order to study the impacts of consumption of alfalfa on the globe's water resources, it is necessary to model the supply chain in order to trace the origins of the product. Visualizing the hidden link between consumption and water use forms the basis for the formulation of new strategies of water governance; in which producers, traders and consumers have a role, not only as direct water users, but also as indirect water users. Therefore, the importance of a water footprint study relies on various reasons: a national government that imports alfalfa hay may be interested in knowing its dependency on foreign water resources, or a local government may be interested to know the sustainability of water use in the areas where import products originate.

In essence, the water footprint of a product is the total volume of fresh water that is used directly or indirectly to produce the product, considering water consumption and pollution in all steps of the production chain. The accounting procedure is similar to all sorts of products, including the agricultural, industrial or service sectors. The water footprint of all products is formed by a green, blue and grey component, and in the case of agricultural products, it is expressed in $m^3\ t^{-1}$ or liters kg^{-1} (Hoekstra, Chapagain, Aldaya, & Mekonnen, 2011).

In the scientific literature there are two parallel developments: the methodology of the Water Footprint Network (WFN), and on the other hand, the water footprint estimated as part of the Life Cycle Assessment (LCA), which developed comprehensive methodologies to include environmental impacts related to water in LCA studies and framed the international standard 14046 on water footprint (ISO, 2014). These approaches have been in conflict in the past few years. Both methods have the goal to preserve water resources, but in different ways. The LCA estimates the potential environmental impacts of human activities on climate change, human respiratory impacts, land use, etc., including water use. LCA calculates quantitative impact indicators related to global warming, eutrophication, acidification and toxicity to human and ecosystems. The LCA method focuses on the sustainability of products, with a comprehensive approach, whereby water (LCAwater) is just one area of attention among others (e.g., carbon footprint, land use). On the other hand, the WFN method addresses freshwater resources appropriation, including the quantification and mapping of the three distinct types of water use: the blue, grey and green water footprints. WFN focuses on analyzing the sustainable, efficient and equitable allocation and use of freshwater in both local and global context with either a product, consumption pattern or geographic focus (Boulay, Hoekstra, & Vionnet, 2013).

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Mekonnen and Hoekstra (2010) quantified the green, blue and grey water footprint of 126 crops in the world, for the period 1996-2005. They used a gridbased dynamic water balance model to calculate crop water use over time, taking into account the daily soil water balance and climatic conditions for each grid cell, including the water pollution associated with the use of nitrogen fertilizer in crop production. They also calculated the water footprint of more than two hundred derived crop products, including various flours, beverages, fibres and biofuels, using the WFN method. Nevertheless, alfalfa was not included in this study.

There is little research on the water footprint of alfalfa. Fulton, Cooley & Gleick (2012) reported that alfalfa has the second greatest water requirements in the state of California, one of the crops that provide the primary inputs to California's meat and dairy industry. It also supplies the demand for alfalfa as animal feed to the expanding global dairy industry, particularly in China, Japan, and the United Arab Emirates (WFN, 2015). Other authors study the water footprint from the demand side in dry areas (Mojtabavi, Shokoohi, Etedali, & Singh, 2018).

Objectives: The objective of this work was to assess the green, blue and grey water footprints of alfalfa hay, produced in both rainfed and irrigated systems, in Córdoba, central Argentina, in dry, wet and neutral periods.

MATERIALS AND METHODS: The research followed the method of Hoekstra et al. (2011), which assesses the amount of water used in production. It calculates the quantity of surface water and groundwater required to produce a good (Blue Water Footprint), the volume of rainwater necessary for the crop (Green Water Footprint) and the amount of freshwater needed to dilute the wastewater generated, in order to maintain water quality, as determined by local regulations (Grey Water Footprint).

Blue Water Footprint (**Blue**) is "*the volume of surface and groundwater consumed as a result of the production of a good or service. Consumption refers to the volume of freshwater used and then evaporated or incorporated into a product. It also includes water abstracted from surface or groundwater in a catchment and returned to another catchment or the sea. It is the amount of water abstracted from groundwater or surface water that does not return to the catchment from which it was withdrawn*" Green Water Footprint (**Green**) is "*the precipitation on land that does not run off or recharge the groundwater but is stored in the soil or temporarily stays on top of the soil or vegetation. Eventually, this part of precipitation evaporates or transpires through plants. Green water can be made productive for crop growth (although not all green water can be taken up by crops, because there will always be evaporation from the soil and because not all periods of the year or areas are suitable for crop growth)*". The Grey Water Footprint (**Grey**) of a product is "*an indicator of freshwater pollution that can be associated with the production of a product over its full supply chain. It is defined as the volume of freshwater that is required to assimilate the load of pollutants based on natural background concentrations and existing ambient water quality standards. It is calculated as the volume of water that is required to dilute pollutants to such an extent that the quality of the water remains above agreed water quality standards*" (Hoekstra, Chapagain, Aldaya, & Mekonnen, 2011).

The area under study included 62,516 ha for pure alfalfa and 6,111 ha of mixed pasture, concentrated in the Departments of Rio Segundo, Tercero Arriba and Río Primero (Córdoba, Argentina). The average temperature is 16.5 ° C, with a frost-free period of 255 to 270 days and average rainfall of 650 mm, seasonal distribution monsoon type. 67.2% of the soils are class III, suitable for agriculture. The class VI and VII soil types for grazing occupy 28.1%, while the rest corresponds to land not suitable for agricultural use. In this area there are two milk basins: Centro, and Villa María, with 18.9% and 14.7% of dairy farms, respectively. The production of alfalfa in this area has a relevant participation within the distribution of implanted crops. For the production of alfalfa, a soil analysis is performed before sowing, to determine the fertilization needs. It usually requires the application of phosphorous fertilizer. Another soil analysis is conducted every year to help maintaining the fertility. The seeding density is 12 kg per hectare of inspected, inoculated and pelleted seed (with resistance to pests and diseases). Direct sowing is done in March, in deep, well-drained soil, with a pH of 6.5 to 7.5, low amount of stubble on the surface, with special care in achieving a uniform sowing depth (0.5 to 1.5 cm). Before seeding, a chemical control of weeds is done, as well as the use of post-emergent herbicides and aphicides. The useful life of the alfalfa crop assumed in this study is three years. Most of this area was devoted to the production of both prismatic and round bales. The crop management is described in Barberis et al. (2015). The useful crop life considered for this model was three years, with a dry matter yield of 12, 15 and 13 t ha^{-1} $year^{-1}$ of for the first, second and third year respectively. The small prismatic bales had an average weight of 22 kg, while round and large prismatic bales weighted 500 kg. For the production of alfalfa under irrigation, the work of Barrenecha et al. (1999) was used as a reference, which reported average yield differences of 48.21% above the rainfed crop. In order for this model to be representative and to reflect the variability of weather, the production of alfalfa was studied during a dry period (2003, 2004 and 2005), a neutral period (2006, 2007 and 2008); and a wet one (2014, 2015 and 2016).

The software Cropwat 8.0 (FAO, 2009) was used to estimate the water requirements, based on weather, soil and ecophysiological variables. The climatic data was obtained from the nearest and most representative meteorological stations of Manfredi, Pilar and Córdoba. The edaphic variables were defined according to the INTA's Soil Atlas (Cruzate et al., 2018), while the ecophysiological variables contained in the Cropwat / FAO database were reviewed with current data. The first step was to calculate the reference evapotranspiration (ETo) and crop water requirements. Although several methods exist to determine ETo, the Penman-Monteith Method has been recommended as the appropriate combination method to determine ETo from climatic data on temperature, humidity, sunshine and windspeed. Specifically, Cropwat required the input of climatic, crop and soil data, as indicated in Table 1.

Table 1: Input data required by the software Cropwat

CLIMATIC DATA	CROP DATA	SOIL DATA
Maximum temperature (ºC)	Crop coefficient (Kc)	Soil type
Minimum temperature (ºC)	Phenological stages (days)	Moisture content (%)
Average temperature (ºC)	Seeding date	Maximum infiltration (mm day^{-1})
Precipitation (mm/ha)	Root depth (cm)	Maximum root depth (cm)
Relative humidity (%)	Crop height at harvest (cm)	Initial soil moisture content (%)
Sunshine hours (h)	Permanent wilting point (%)	
Average daily windspeed (m sec^{-1})	Crop yield (t ha^{-1})	

With this information, the software calculates the specific crop evapotranspiration (ETc), as Etc = ET0 * Kc (in mm day^{-1}), where Kc = Crop coefficient. The following step is to calculate the crop water requirement (CWR) or Green Water Footprint (**Green**), in m^3 ha^{-1}, as CWR = Σ Etc (accumulated over the entire growth period). The last step in Croptwat is to calculate the water need, the irrigation requirement, or Blue Water Footprint (**Blue**), as the crop water requirement (CWR) minus the effective precipitation: BWF = CWR - effective Ppt.

Finally, in order to determine the Grey Water Footprint (**Grey**), the application of phosphorus fertilizer was considered, establishing a leaching coefficient of 3% and a maximum allowed concentration of 4 m*u*g L^{-1} (Franke et al., 2013).

RESULTS: Table 2 shows the results obtained for the Green, Blue, Grey and Average Water Footprints in the production of alfalfa in rainfed and irrigated regimes respectively, for dry, neutral and wet years.

Table 2. Water footprint (m^3 of water per t of hay).

		RAINFED				IRRIGATED				
		Green	Grey	Total	**Avg**	Green	Blue	Grey	Total	**Avg**
Dry	2003	758	91	849	859	140	382	37	560	774
	2004	902	49	951		473	341	30	844	
	2005	728	48	776		619	264	35	918	
Neutral	2006	728	84	812	881	247	317	37	601	728
	2007	826	47	874		440	293	30	763	
	2008	908	48	956		482	303	35	819	
Wet	2014	562	75	638	819	355	221	37	614	743
	2015	812	38	850		488	227	30	745	
	2016	927	42	969		683	151	35	869	

Even though there is not much scientific information about the water footprint for alfalfa, the estimates from the California Agricultural Statistics Office (2012) show that the average water footprint of alfalfa hay in California is 950 m^3 t^{-1}. Therefore, the average value of for 800 m^3 t^{-1} for Argentina is 15% lower than California, which might be a competitive advantage in markets willing to pay a premium for the reduced water footprint.

Regarding virtual water, a quick estimation indicates that if all the exports from Argentina for the year 2017 were from a rainfed production, the exported virtual water would have been 50 million m^3, whereas it would have been 44 million m^3 if irrigated (Table 3).

Table 3: Estimation of the virtual water contained in alfalfa hay exports

	Tons of hay	VIRTUAL WATER (m^3 YEAR^{-1})	
		Rainfed	Irrigated
2013	46,976	40,058,158	35,137,474
2014	36,758	31,344,894	27,494,535
2015	19,194	16,367,428	14,356,877
2016	23,406	19,959,154	17,507,402
2017	58,848	50,181,847	44,017,585

CONCLUSIONS: The average water footprint of alfalfa hay in Argentina ranged between 819 and 881 m^3 t^{-1}. This variability is due to changes in rainfall between years. On average, the total water footprint increased 5% in dry years and 8% in neutral years. When the crop was irrigated, the average footprint decreased to a range between 728 and 774 m^3 t^{-1}. On average, the total water footprint increased 4% in dry years. The irrigation decreased the total average water footprint an 11% in dry years, 21% in average years, and 10% in wet years. This study successfully characterized the water footprint of alfalfa hay production in Córdoba, Argentina and opened the way for further research. Simultaneously, it draws the attention to the amount of virtual water exported annually.

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