Water Footprint in paddy rice systems. Its determination in the provinces of Santa Fe and Entre Ríos, Argentina

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ABSTRACT
In the context of social responsibility and, of the directives aimed at an integral management of natural resources, the Water Footprint (WF) has been widely spread as an indicator that contributes to a safe and sustainable use of water. The purpose of this study was to determine the WF for rice production (WF<sub>R</sub>) in two rice-growing areas in Argentina: central-east Entre Ríos and Santa Fe. The calculation was made using the methodology proposed in The Water Footprint Assessment Manual, according to which the WF of a crop, in this case rice, represents the relation between the amount of water satisfying the evapotranspiration demand (CWU) and the field productivity. The WF has three components: green (WF<sub>green</sub>), associated with rain used by the crop (CWU<sub>green</sub>); blue (WF<sub>blue</sub>), related to underground or surface water that fulfils the evapotranspiration demand (CWU<sub>blue</sub>); and grey (WF<sub>grey</sub>), related to the volume of water required to dilute the residues of pollutants generated from the crop production. To estimate the CWU<sub>blue</sub> and CWU<sub>green</sub>, a rice water balance model (RWM), specifically developed for continuous flooding irrigation, was applied. Based on daily data of precipitation, crop evapotranspiration and soil variables the model allows calculating gross irrigation depth, surface runoff due to precipitations, variation of water stored in the soil, and deep percolation. Four agricultural seasons were assessed: 2009/2010, 2010/2011, 2011/2012, and 2012/2013. In Entre Ríos, WF was 987 m<sup>3</sup> ton<sup>-1</sup> (44% WF<sub>green</sub> and 56% WF<sub>blue</sub>), whereas in Santa Fe it was 846 m<sup>3</sup> ton<sup>-1</sup> (36% WF<sub>green</sub> and 64% WF<sub>blue</sub>). In accordance with related work in the region, WF<sub>grey</sub> was not considered. Although only CWU is part of the WF calculation, the other components of the water balance are necessary for rice production. The RWM model determined the consumptive use of the crop and distinguished blue water from green water, besides calculating the other parameters of the water balance. This made possible to show the inefficiencies in the system since precipitations are not fully used. The WFs, together with these components, is useful to make comparisons between different regions and it is a tool to promote water saving, provided that it is complemented with specific policies, such as the differential application of irrigation taxes or electric power rates.

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1. Introduction

Global water resources are heavily exploited for food production; therefore, their demand is expected to increase in the future as population grows and its per capita use rises (Bocchiola et al., 2013; Curmi et al., 2013). Currently, agricultural production accounts for about 70% of water withdrawals (Chen and Chen, 2013; Curmi et al., 2013; Molden et al., 2007).

As with the trade of commodities, regions trade water in virtual form that is needed for production, which is known as virtual water (WF) (Liu et al., 2015). It represents nearly 30% of the global water withdrawal and it is estimated that 43% (508 Gm<sup>3</sup>) of the international VW trade is embodied in food trade (Chen and Chen, 2013). Thus, the VW flow plays a significant role in redistributing water resources between nations; it implies the exchange of water through commodities, from regions where it is relatively abundant and low-cost to regions where it is scarce and expensive, and its use competes with other priorities (Chen and Chen, 2013; Pengue, 2005). On a continental scale, Asia, Europe, and Africa are considered net importers, while Oceania, North America, and South America are net exporters (Konar et al., 2011). With respect to

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countries, Australia and Argentina are the top two largest virtual
water exporters, this associated, mainly, with a large area of crop-
land on a per capita basis (Liu and Yang, 2010). In Argentina, it is
estimated that at least 46,000 Mm\(^3\) of water are exported per year,
whereas only 3100 Mm\(^3\) are imported (Hoekstra and Hung, 2002;
Sánchez, 2010).

A key concept to VW quantification is the Water Footprint (WF), which is a comprehensive indicator of the appropriation of fresh water (Liu et al., 2015) that has been brought into the science of water management to show consumption patterns and global dimensions in good water governance (Hoekstra et al., 2011; Vanham et al., 2013). It represents water consumption volumes by source (green and blue WFs) and polluted volumes (grey WF) by type of pollution (Hoekstra et al., 2011; Wang et al., 2014).

In Argentina, the main export agricultural products are grown under rainfed conditions; therefore VW trade is based on green water\(^2\) whereas it implies negligible blue water\(^3\) (Aldaya et al., 2011). Moreover, Argentina is one of the countries with the highest negative balance of green water, mainly due to wheat crop (Fader et al., 2011).

However, rice (Oryza sativa L.) crop plays a significant role in blue water trade, since it is one of the largest water consumers in Argentina. Depending on the water management and the type of source used (rivers, dams, deep wells), the requirement varies from 13,200 m\(^3\) ha\(^{-1}\) to 19,000 m\(^3\) ha\(^{-1}\) (Duarte et al., 2006; Marano, 2014). Furthermore, Argentina is ranked eleventh among the world’s largest rice-exporting countries. During years 2009, 2010, and 2011, the average production reached 1,441,795 tons and 41% of this amount was exported (FAOSTAT, 2013).

The province having the largest rice sown area in the country is Corrientes, accounting for 44.5% of the total area, followed by Entre Ríos with 29% and Santa Fe with 18.5%. The rest is distributed between the provinces of Formosa and Chaco (Fig. 1, ACPA, 2013).

The irrigation method most widely used for rice production is Continuous Flooding (CFr).

Irrigation starts 30 days after the sowing, during the tillering stage, and the soil is flooded until reaching physiological maturity (Quintero, 2009; Filippi et al., 2013).

Water supply for rice irrigation comes from different sources. In Santa Fe, it is withdrawn from surface sources, precisely from San Javier River, while in Entre Ríos it depends on the region (Fig. 2): farmers from the central-east obtain it from groundwater, through deep wells; and farmers from the north-west obtain it from rivers and streams (Engler et al., 2011; Filippi et al., 2013).

The purpose of this research was to determine the Water Footprint of rice (WF\(_R\)) and the consumptive water use in its primary production stage (from sowing to harvesting), to distinguish the blue and green water components of WF\(_R\), and to quantify the volume of virtual water that is exported through the rice grain. The reason for conducting this study was the importance of rice in the above-mentioned provinces and the lack of information about these topics in the region.

\section*{2. Methodology}

The WF\(_R\) was calculated following the methodology proposed in The Water Footprint Assessment Manual (Hoekstra et al., 2011). It was estimated specifically for rice in its primary production cycle considering the average of four rice seasons (2009/2010, 2010/2011, 2011/2012, and 2012/2013). The study was focused on two geographical regions: the rice-growing area of the province of Santa Fe, including San Javier and Garay departments (Fig. 2a), and central-east of the province of Entre Ríos, covering Concepción del Uruguay, Colón, San Salvador, and Villaguay departments (Fig. 2b).

The WF indicator for a product, in this case rice, is the result of the sum of the three components (Hoekstra et al., 2011):

\begin{equation}
\text{WF}_{\text{R}}(\text{m}^3 \text{ton}^{-1}) = \text{WF}_{\text{green}} + \text{WF}_{\text{blue}} + \text{WF}_{\text{grey}}
\end{equation}

where WF\(_{\text{green}}\), WF\(_{\text{blue}}\), and WF\(_{\text{grey}}\) are green, blue, and grey WFs, respectively.

WF\(_{\text{grey}}\) refers to the volume of fresh water required—according to water quality standards—to assimilate a load of pollutants from residues or waste water that has been used to obtain a product (Mekonnen and Hoekstra, 2011; Salmoral et al., 2011). In order to assess this component, data published by Díaz and Lenzi (2009, 2010), and Díaz et al. (2011) were considered. These data belong to a research conducted consecutively during three agricultural seasons (2008/2009, 2009/2010, and 2010/2011), in which the impact

\footnotesize{\(^2\) It refers to the water coming from rainfall.\n\(^3\) It refers to the water coming from surface (rivers, lakes) and groundwater sources (aquifers).}