Water use efficiency gap on dairy systems in humid and semiarid region of Argentina

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Abstract
The agricultural process of the Argentine humid pampas forces the intensification and relocation of cattle and dairy systems into subhumid and semiarid region to keep their competitiveness. In consequence, there is an increasing water demand scenario, especially intense in these fragile areas. Water footprints of representative dairy systems from basins of La Pampa, San Luis and Santa Fe provinces, with different degrees of intensification have been assessed using Life Cycle Assessment (LCA) methodology, including virtual water indicators. Livestock feeding, particularly, supplements is the main contributing factor to the water footprint of the system product. However, the minor indicators resulted from the supply of intensive systems, revealing that system productivity compensates water use intensity. This negative relationship between productivity per hectare and water footprint, reveals the importance of intervention to reduce technological gaps, mainly in dairy basins of the semiarid region of Argentina.

Introduction
The agricultural sector in Argentina is suffering a rapid productive transformation associated with the agriculturization of land use, intensification and relocation of livestock based systems. Certain dairy basins of the semiarid and subhumid region are not excluded of this process and have received this kind of investment, attracted by low land prices and groundwater irrigation possibilities. For the period 1994-2007 the surface implanted with agricultural farming was duplicated at national level, reaching 22.8 million hectares (70% correspond to soybean). In the humid *Pampas*, this increase has occurred at the cost of land dedicated to the cattle ranch, which lost 8.8 million hectares but only 3 million heads were moved towards other regions of the country: 60% towards the northwest and 30% towards La Pampa and San Luis provinces. Particularly in semiarid zones the intensification processes are developed on the basis of water resources, being significant the incorporation of new surfaces with irrigation from superficial and underground sources. Only in San Luis province, the surface under irrigation by center pivot go from 14,940 has in 2002 to 33,216 has at the present time.
Milk activity in both provinces has also been intensified in this process. In La Pampa province the number of dairy farms grew by 15% during that period, with the consequent increase in milk production, reaching 140 million liter/year and reinforcing the expansive tendency of the activity. It is remarkable that 16% of the dairy farms concentrate 55% of the provincial production and five mega dairy farms centralize more than 30% of it.
Although in San Luis the milk activity does not have still a significant dimension, it stands out the existence of two relocated mega dairy farms in zones under irrigation that concentrate 50% of the provincial production. Besides, in the humid *Pampas* there is a decrease in stock and dairy farms, but the 16% of growth in aggregate production for the period, was reached by an increase in size of herds and stocking due to the incorporation of agricultural area as a strategy to keep its competiveness. In consequence, there is an increasing hydric demand scenario, especially intense on fragile areas.
There are several LCA studies on dairy chains that focus on the assessment of the potential improvement of their environmental performance, analyzing the sensitivity of impact indicators such as: energy use, emissions of greenhouse gases, acidification, eutrophication, photo-oxidants and ecotoxicity, but water depletion is not considered. Basset-Mens *et al*. (2009) assess different intensification scenarios of dairy systems and Hospido *et al.* (2003) alternative processes of milk production. Overall, the primary production of milk, specifically the agricultural phase, followed by the packaging, is identified as critical in the environmental impact of life cycle of milk. By other hand, there is a vast inventory of water footprints of crops and animal products for many countries, including milk products of Argentina (Chapagain and Hoekstra, 2003; Mekonnen and Hoekstra, 2010).

The first inventories were built with the aim of determine the volumes of virtual water flows from international trade in agricultural products (Hoekstra and Hung, 2002), animals (Chapagain and Hoekstra, 2003), and the analysis of water footprints of nations (Chapagain and Hoekstra, 2004). But, is necessary to consider system and geographical particularities and heterogeneities between basins to assess its environmental changes.
The aim of the study is to determine and compare water use efficiency of dairy systems for different intensified scenarios from humid and semiarid milk basins of Argentina in order to monitor this productive transformation process.

Material and Methods
Water footprints of three representative dairy systems with different degrees of intensification, scale and use of water resource from basins of La Pampa, San Luis and Santa Fe provinces were determined and contrasted. Their water use efficiency in terms of milk production has been assessed using Life Cycle Assessment (LCA) methodology, including virtual water indicators. Inventories of water consumption of the feed chain and production of grain for animal supplementation was determined according to the methodology developed by Hoekstra *et al.* (2011) (1), using AGROECOINDEX® model, considering both blue *–underground*- and green *–precipitations*- water origins. Virtual water content of supplements was obtained from AGROECOINDEX® database, as well as the determination of the consumption of animal drinking water. Efficiency parameters of farm irrigation systems were considered. The volume of water used in the process of pulverization of agricultural chemicals to crops was estimated by labels of products and average technical specifications. Inventory data for milking routine process was built based on data collected by measurements in situ.
The water footprint of a product is defined as the total volume of freshwater used (directly or indirectly) to produce it; it is estimated taking into account consumption and pollution of water in all phases of the production chain (Hoekstra *et al*., 2011). Water use in animal feeding corresponds to the sum of the evaporative demands of pastures and crops grown in farm and imported by supplements.

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

Specifically, the water footprint of dairy milk can be expressed by equation (1), where $WF_{prod}\,(p = raw\ milk)$; the product fraction $f_p(p,i) = 1$; $WF_{proc}(raw\ milk) = {}^{CRo}/_{Y^{R,S}}$; CRo: water consumption in milking processing routine (m3/year); $Y^{R,S}$: dairy milk production (L/year). $WF_{prod}(i)$ is given by the total virtual water consumption of animal feeding, $VWT^{R,S}$:

$$WF_{prod}(i) = \left(\frac{VWT^{R,S} \times f_v(raw\ milk)}{Y^{R,S}}\right) \times\, f_v(p) \quad (2)$$

In this paper, for dairy systems the assignment coefficient -the *value fraction* $f_v(p)$- was estimated considering only two products of the cow: milk and meat, taking the total annual market value of both products

Results
Livestock feeding, particularly, supplements is the main contributing factor to the water footprint of the system product. However, the minor indicators resulted from the supply of intensive systems, revealing that system productivity compensates water use intensity; in the case of San Luis basin, 983 liters of water per liter of raw milk, under the small scale intensive system, 782 liters of water per liter of raw milk from the industrial dairy farm system of La Pampa, and 915 liters of water from the extensive/modal system of Santa Fe. The ecoefficiency gap from the representative system of each basin (Modal) was 55%, 24% and 22% respectively.

Table 1 – Inventory data for dairy systems: Animal feeding, Milking process and Virtual Water

	San Luis				La Pampa				Santa Fe		
	Modal	Extensive	Intensive S	Mega	Modal	Extensive	Intensive S	Mega	Extensive Modal	Intensive S	Large scale
Dairy cows -in production	65	140	98	1.180	196	500	66	2.185	380	179	518
Annual production, L/year	438.913	1.058.500	983.675	10.466.010	1.708.200	3.923.750	402.960	21.772.433	3.051.400	1.371.888	3.819.214
Milk production per ha, L/ha/year	**1.562**	**3.308**	**15.133**	**15.369**	**4.495**	**4.563**	**5.233**	**17.349**	**10.976**	**9.527**	**10.609**
Irrigation, total m3/year	1.442.448	no	700.920	5.280.000	no	no	no	no	no	no	no
Animal feeding											
On-Farm Pasture Water consumption , m3/year	**961.579**	**1.292.898**	**462.280**	**5.953.030**	**1.966.880**	**3.249.295**	**374.682**	**7.207.465**	**1.556.160**	**828.976**	**2.027.874**
Brought-in feed supplements Water Consum., m3/year	**107.800**	**586.986**	**584.584**	**5.748.895**	**0**	**1.606.000**	**456.250**	**10.647.416**	**1.340.339**	**881.060**	**2.007.410**
Drinking Water -total, m3/year	**3.395**	**7.254**	**2.861**	**36.956**	**2.592**	**15.513**	**2.592**	**67.425**	**12.906**	**5.864**	**18.706**
Water use for crop protection-Pulverizations, m3/year	**47**	**78**	**14**	**221**	**85**	**143**	**13**	**520**	**92**	**53**	**110**
Total Water consumption per ha, m3/ha/year	**3.818**	**5.898**	**16.150**	**17.238**	**5.183**	**5.664**	**10.825**	**14.281**	**10.466**	**11.916**	**10.669**
Milking process											
Water consumption in milking process , L/day	**2.655**	**1.159**	**2.884**	**152.601**	**6.209**	**31.391**	**3.246**	**310.500**	**43.904**	**55.257**	**51.984**
Total Water consumption in milking process, m3/year	**969**	**423**	**1.018**	**55.699**	**2.266**	**11.458**	**1.185**	**113.333**	**15.805**	**19.892**	**18.714**
Total W. cons. milking process, per milk unit, *Lwater/Lmilk*	**2,2**	**0,4**	**1,0**	**5,3**	**1,3**	**2,9**	**2,9**	**5,2**	**4,0**	**5,8**	**4,9**
Totals											
System Water consumption per milk unit, m3/L/year	**2,27**	**1,69**	**1,02**	**1,06**	**1,08**	**1,18**	**1,86**	**0,82**	**0,95**	**1,25**	**1,06**
Value product fraction	0,96	0,95	0,96	0,95	0,9	0,95	0,9	0,95	0,96	0,94	0,95
Dairy Milk-Virtual Water, water L/milk L.	**2,182**	**1.609**	**983**	**1.007**	**975**	**1.125**	**1.676**	**782**	**915**	**1.176**	**1.008**

In both provinces, it is observed that further intensification of the system corresponds to a higher proportion of external virtual water imported by supplementation (external DM). This source is the main contributing factor in the virtual water (VW) indicator for intensive systems, more than 50% in all cases[1] (Figures 1). In the case the most intensified system of San Luis (Mega dairy), blue water consumption is higher than on-farm green water, an aspect that reveals the reality of the need for complementary irrigation systems for dairy farming in the semiarid region (Figure 1a).

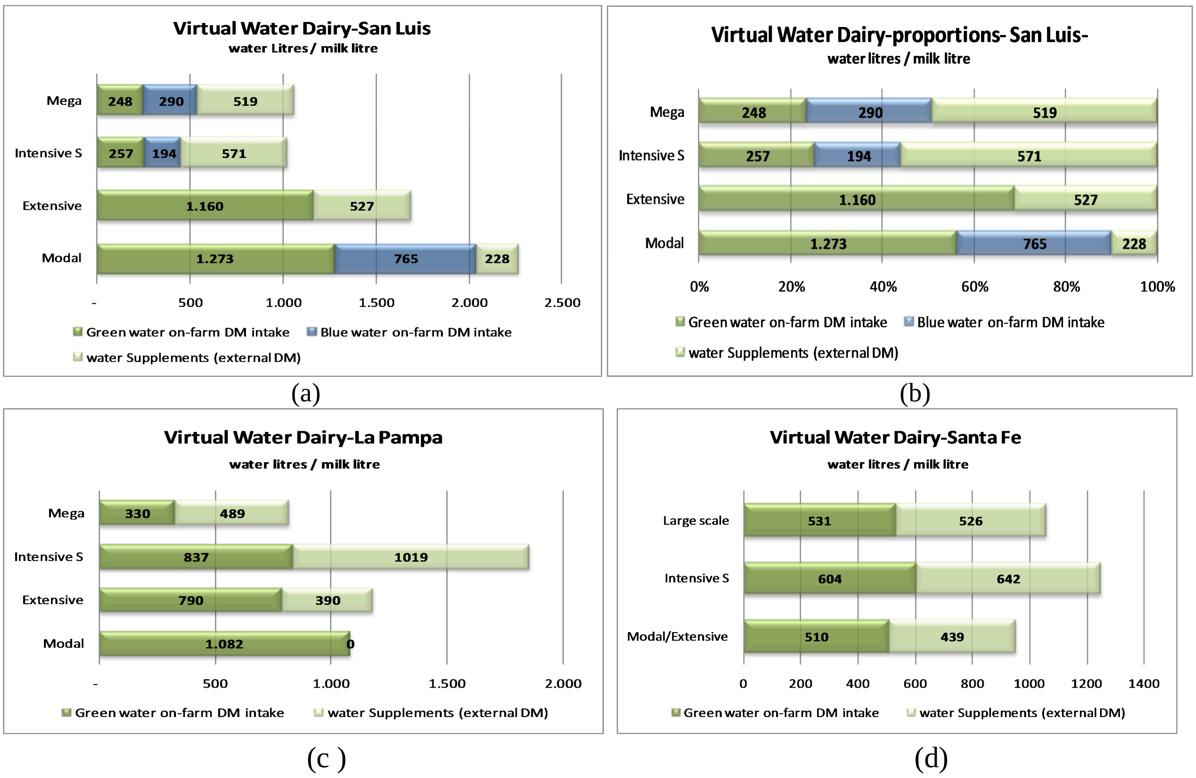
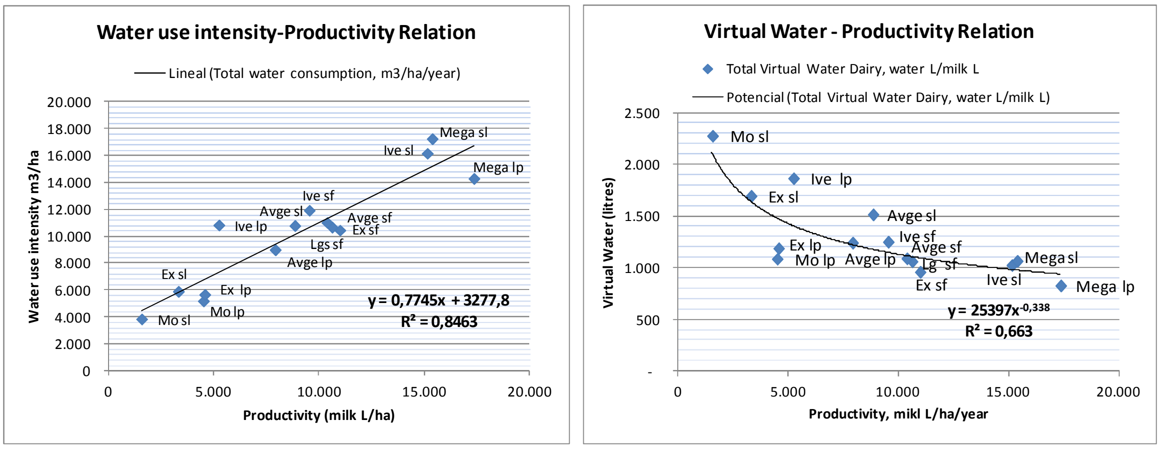


Figure 1 - Virtual blue and green water in primary production component: (a) San Luis study cases, (b) percentage share, (c) La Pampa study cases, (d) Santa Fe study cases.

[1] Modal case of La Pampa produces on-farm all the supplements used for feeding.

A first remarkable aspect is the strong positive relationship between intensity of water use (water use m3/ha/year) and system productivity (milk production / ha / year), which suggests that, on average, each additional liter of milk per hectare of the system corresponds to 0.77 m3 of virtual water added (Figure 2a). This fits with the results presented on Table 1, as noted, the main determinant of VW indicator is water consumption at animal feeding stage (production or import of DM).



(a) (b)

Figure 2 –(a) Intensity of water use, m3/ha/year **- Productivity of the system,** L milk / ha / year **Relationship (b) Virtual Water,** Lwater/L milk / year **- Productivity of the system,** Lmilk/ ha / year **Relationship**

The second relationship, represented in Figure 2b, shows that low Virtual Water indicators are related to higher productivity of the systems. The most water efficient dairy systems (lower VW) are those in which their productivity compensate the intensity of resource use: Mega dairy farms and San Luis-Intensive S system (Ive SL), but extensive/modal en Santa Fe. The conceptualization of the inverse function of Virtual Water, expressed in liters of milk per mm, as a proxy of the Global Water Productivity of the dairy system[2]-; allow to explain these aspects of the heterogeneity of eco-efficiency of such water use, in consistency with Mekonnen and Hoekstra (2010) results:

(i) intensive systems with high productivity (Mega and Intensive S dairy farms) had the lowest indicators of total VW; (ii) main contributing factor to total VW was the green water from external feed. Suggesting that: (iii) while virtual water productivity of external feeds is less than the observed for other sources of feed within the system, its existence in the animal feed ration contributes significantly to the global water productivity of the system as a whole.

Conclusion and perspectives

Methodological contribution was made to the convergence between the LCA methodological framework and the implementation of virtual water and water footprint indicators for environmental impact assessments. The evidence of a negative relationship between productivity per hectare and water footprint, reveals: i. the importance of intervention to reduce technological gaps, mainly in dairy basins of the semiarid region of Argentina; ii. the consideration of system heterogeneities on water footprint estimates to monitor territorial sustainability dynamics.

References

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2 $GWP^{S,R} = \frac{1}{WF_{prod}\,(raw\,milk)}$.