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Weighting the impacts to stream water quality in small basins devoted to forage crops, dairy and beef cow production

Guillermo Chalar[a,b,*], Patricia Garcia-Pesenti[a], Macarena Silva-Pablo[a], Carlos Perdomo[b,c], Vanesa Olivero[a], Rafael Arocena[a]

[a] Instituto de ecología y ciencias ambientales, Facultad de Ciencias, Universidad de la República, Iguá 4225 piso 9, CP 11400 Montevideo, Uruguay
[b] Departamento de suelos y aguas, Facultad de Agronomía, Universidad de la República, Uruguay. Garzón 780 CP 12900 Montevideo, Uruguay
[c] Faculty of Agronomy, Universidad de la República, Uruguay

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ABSTRACT

Livestock for beef and milk production are important economic activities worldwide. These require intensive cultures of pastures and forages, with the consequent impacts on water quality in downstream rivers and reservoirs. Monthly temporal variation of nutrients and water quality were assessed along one year at basin scale (basin area < 3500 ha). Several indicators of farming intensity (number of dairy cows and beef cows, percentage of area devoted to crops) and management practices (effluent treatment, fertilizer application) were related to the export of nutrients and sediments from the basins and with the water quality of receiving streams using partial least square regression analysis (PLS). According to PLS analysis, the most relevant variables to explain water quality degradation and high export coefficients of nutrients and sediments, were the percentage of basin area dedicated to crop activities and the density of dairy cows without effluent treatment. Beef and dairy cows had an important local impact on stream water without animal access restrictions. We also propose some hypotheses regarding the transport pathways of sediments and nutrients to streams. Our results demonstrate the urgent need to implement best management practices at the farm scale within each basin, focusing on: adequate phosphorus fertilization, implementation of a complete dairy effluent treatment system and animal restriction to fluvial channels.

1. Introduction

The intensification of agriculture since the middle of the last century has caused an increase in diffuse sources of pollution impacting on aquatic ecosystems. Such diffuse sources may currently represent the largest of inputs of nitrogen, phosphorus and sediments into surface waters (Carpenter et al., 1998; Sun et al., 2012; Giorgini and Zingales, 2013). The combination of these inputs with point sources and aquatic habitat alterations (dam construction, stream channels and riparian zones degradation), have contributed to the deterioration of water quality and the eutrophication of surface waters (Zalidis et al., 2002; Brainwood et al., 2004; Poor and McDonnell, 2007; Li et al., 2008). Most abundant forms of nitrogen are usually soluble in water. Main anthropogenic sources of inorganic nitrogen (mainly nitrates and ammonium) are chemical fertilizers and mineralization of organic compounds, whereas dissolved organic nitrogen is relevant in agricultural soils fertilized with manure. Main transport route for both forms of nitrogen is leaching from surface soils and subsurface flow to aquatic systems (Hatch et al., 2002; Melland et al., 2012; Mellander et al., 2015). On the other hand, it has been seen that dissolved and particulate phosphorus transport is dominated by surface runoff (Haygarth and Jarvis 1997; Bowes et al., 2009). However, recent studies show that subsurface transport of soluble reactive phosphorus can be very important in watersheds with well-drained soils (e.g. sandstone geology) and also from riparian wetlands (Mellander et al., 2012; Dupas et al., 2015). Identification of nutrient and sediment sources in terrestrial ecosystems and transport routes to surface waters are very relevant for the implementation of mitigation measures within the basins.

Dairy farming is a demanding activity that combines intensive forage production with intensive livestock grazing. High concentrations of animals produce large amounts of manure that is often not adequately treated, thus representing an important source of organic matter, nutrients and other compounds (Ledgard et al., 1998; Bewsell et al., 2007). Moreover, forage production systems that supplement animal diets may require large amounts of phosphorus and nitrogen fertilizer. A proportion of these nutrients are mobilized according to

* Corresponding author.
E-mail addresses: gchalar@fcien.edu.uy (G. Chalar), 21patriciagarcia@gmail.com (P. Garcia-Pesenti), macaren.sdp@gmail.com (M. Silva-Pablo), chperdomo@gmail.com (C. Perdomo), vanesa.olivero@gmail.com (V. Olivero), rarocena@fcien.edu.uy (R. Arocena).

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specific export coefficients, which depend upon many features such as topography, soil type, storm events and management practices (Kyllmar et al., 2006; Shore et al., 2014). Best management practices were proposed decades ago to mitigate the environmental impacts of agriculture and livestock (Berten, 1940), but in developing countries and particularly in Uruguay there is a long delay in implementing conservation practices to reverse the deterioration of water quality.

Beef production is the most traditional and relevant productive sector of Uruguay's economy. This activity is historically carried out extensively on natural grassland with low stoking heads but in recent years the production in feddlots has been increasing. In contrast, dairy production has in expanded in the last 20 years. Between 2001 and 2013 the amount of milk sent to processing plants increased from 1,300,000 to 2,014,000 liters while the number of dairy producers decreased from 5100 to 2997. During the same period, the land area devoted to this sector decreased by 12% and the number of cattle increased by 4% (DIEA, 2010; DIEA, 2015); and between 2000 and 2007, 47% of family farmers with land areas smaller than 216 ha had abandoned the activities (García-Préchac et al., 2010).

The aim of this study was to determine the probable cause − effect relationship between production activities (crops, dairy and husbandry) and water quality in unconfined livestock systems at small basin scale (< 3500 ha). We also aimed to identify the practices that most contributed to the export of nutrients and suspended solids to fluvial ecosystems. This information could be used as a basis for implementation of management plans tending to reverse the current process of eutrophication and deterioration of water quality.

2. Methods

2.1. Study area

This study was carried out in the west region of the Santa Lucía River Basin, a watershed located in southern Uruguay that drains into the estuary of Rio de la Plata (Fig. 1). The landscape of the region is gently undulating with very smooth slopes, the relief of all study sub-basins are hills ranging between 50 and 170 masl. Predominant sediments are composed by silt and clays corresponding to moderate-drained bronosolic soils. Basin 10 has areas with crystalline geology and sediments of greater grain size but brunosolic soils are also predominant (OPP, 1992). The sub-basins are located in a region devote to intensive crop production since 1950. Very bad agricultural practices caused high soil erosion rates in the Santa Lucía basin (31 tons Ha^{-1} year-1; OPP, 1992) but are currently still high under the standards of tolerable erosion for these soils of 7 tons Ha^{-1} $year^{-1}$ (OPP, 1992).

Land use within the region largely consists of dairy and beef production and crop agriculture. Mean annual temperature is around 17 °C, while mean annual precipitation is 1100 mm without a rainy or dry season Base flow discharge at headwater streams is low due to low groundwater contribution but may exhibit a rapid increase in discharge during sudden events of high rainfall (Goyenola et al., 2015). The study sub-basins drain into Paso Severino reservoir, the most important source of water for potabilisation in Uruguay; it provides drinking water for the two million inhabitants of the metropolitan area of Montevideo and nearby cities. The reservoir was classified as eutrophic according to annual mean values of total phosphorus (380 μg L^{-1}) and total nitrogen (610 μg L^{-1}) (Arocena et al., 2016).

In a preliminary survey of Paso Severino watershed, we selected eight small sub-basins (watershed area < 3500 ha), devoted to forage agriculture, milking activities and/or beef cow production (basins 1–8) and another two with low land use intensity (non-intensive beef production), as reference for minimal anthropogenic impact (9 and 10) (Fig. 1). All the sub-basins are located within close proximity (~30 km). The location of the ten study reaches with their respective basins is available: Study_basins_and_P_Severino_Reservoir.KMZ

2.2. Characterization of agricultural activities

Land uses were determined using the land cover maps developed by Bartesaghi and Achkar (2008). The crop production intensity was estimated as the percentage of crop area within the study basins. Main crops for animal forage are mixed pastures with different combinations of grasses (Festuca arundinacea, Lolium multiflorum) and legumes (Trifolium repens, Trifolium pretense, Lotus corniculatus, Medicago sativa, Chicorium intibus), although pure stands of annual grasses (Lolium multiflorun, Avena sativa and Sorgum sp) or Medicago sativa are also used. Quantitative and qualitative characterization of main agricultural activities in each basin was performed through verbal surveys of farm owners or managers. One hundred surveys were conducted in accordance with a previously designed form to determine: the techniques used for crops (eg, tillage or no-till planting), fertilizer management, number of dairy cows, milk production (l day^{-1}), number of milking units, type of treatment system of effluents from milking parlors and the number of beef cows. In addition, two open discussion workshops were organized with the participation of farmers, public authorities and scientists. It was obtained in all instances a very good collaboration and participation of those involved. Main sociological results were presented and published in two consecutive congress of the Sociological College of Uruguay (Olivero et al., 2011, 2013). We considered the existence of wastewater treatment when dairy farms had secondary treatment; no tertiary treatment was performed in any of the dairy farms within the study basins. During the samplings the state of conservation of the riparian zone, the presence of cattle drinking points and the facility for livestock access to watercourses were evaluated.

2.3. Physicochemical variables

One stream reach per basin located at the outlet of the main tributary was sampled monthly between September 2009 and August 2010. Each stream reach (50m) was divided into three portions

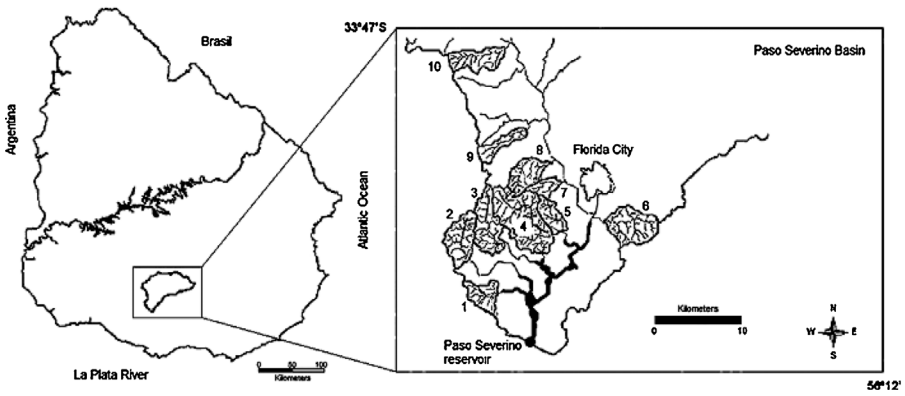

Fig. 1. Study basin locations within the region.