Modeling of land uses to reduce the export of nutrients from dairy production systems to surface waters in the Santa Lucía River basin.

A Castagna[1] – L Rodríguez-Gallego[2] – A Mauttone[3] – F Matonte[3] – O Blumetto[1]

[1]Intituto Nacional de Investigación Agropecuaria (INIA), Uruguay. [2]Centro Universitario Regional del Este, Universidad de la República. [3]Facultad de Ingeniería, Universidad de la República.

1 – Introduction

Loss of water quality in streams is an increasing problem in Uruguay, and dairy production stands out as one of most influential activities in diffuse nutrient losses (Failde et al., 2015). Santa Lucía river basin with a 13,681 km^2 surface, has a high relevance to Uruguayan society because it is the main source of drinking water for metropolitan area of Montevideo, where 60% of country population lives. Intensification of human activities in this area has caused an increase in the eutrophication of surface waters. The report on pollution control and water quality management in this basin (DINAMA-JICA, 2011) estimates that 80% of nitrogen and phosphorus, that reach the water courses, comes from diffuse sources. Dairy production is of great importance in the basin since 38% of the country's dairy farmers are established in this area (Delgado, 2017). According to this background, any improvement of the environmental impacts of this sector is extremely relevant.

When it is intended to maximize productive objectives while minimizing environmental externalities, it is necessary to apply the best available technology and plan the activities in the landscape. Scenarios of different land use allocation in the territory can be built by spatially explicit modeling based on multi-objective approaches, preventing environmental impacts. This is a novel tool that allows to advise public policies and provide technical elements for redesigning production systems to address the environmental challenges that arise (Rodríguez-Gallego et al., 2019). The objective of this work was to develop a spatially explicit optimization model that allows reaching certain levels of dairy production, minimizing the export of phosphorus to the surface waters.

2 – Materials and methods

As a case study a fifth order basin of 114 km^2, located east of San José state (fig. 1), was selected. Dairy production as the main activity inside the basin was the selection criteria. The area was subdivided according to farms limits and its paddocks. Through

photointerpretation of satellite images and field survey, summer land uses of each one of the paddocks were identified.

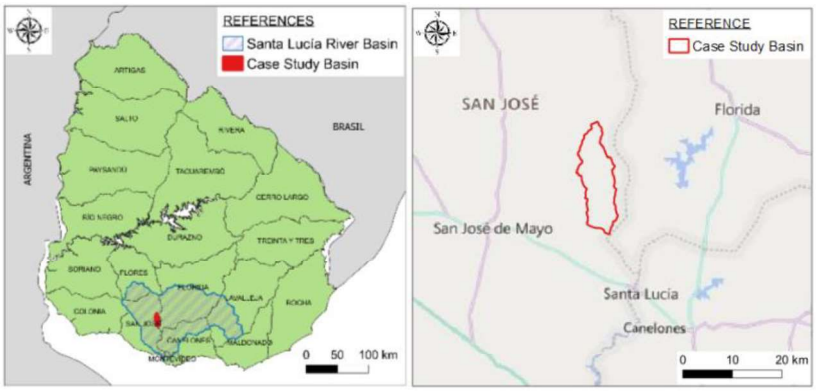

Figure 1. Study area location. At left is indicated the basin of Santa Lucía River. At the right image it is shown the studied basin.

Furthermore, constraints involving allowable crop sequences (duration or seasonality) and number of different crops per farmer were considered. Buffer zones, native forest, afforestation and water bodies were excluded of the modeling area. A geographic information system was built with land uses and spatial restrictions, where model outputs were also displayed

The spatial resolution of the model was defined by the paddock surface, which constitute the typical spatial unit over which a farmer takes land use ~~change~~ decisions. A time horizon of four years was defined, with four season each (autumn, winter, spring and summer) totaling 16 temporal units in the planning horizon. Five model parameters were established: 1) area of the spatial unit (paddock); 2) seasonal phosphorus export coefficient of the crops (kg $P.ha^{-1}$); 3) seasonal dry matter productivity (kg DM. ha^{-1}) of the crops; 4) minimum productivity allowable for any farmer in any season and 5) minimum (maximum) number of different crops allocated to any farmer in any season.

Crops seasonal productivity and its phosphorus export coefficient were taken from a literature review. The restriction of dry matter productivity was established based on a minimum per station to ensure sustainability of dairy farmers (6,000 kg $DM.ha^{-1}.year^{-1}$, divided unevenly into the different seasons). The problem was modeled as a combinatorial optimization one, where decisions are the crop to be allocated at each spatial unit within a discrete planning horizon, which was solved by applying a two-phase heuristic.

3 – **Results – Discussion**

The basin was composed of 42 farmers, which were subdivided into 792 paddocks with an average area of 13 ha. More than 80% of the natural vegetation had been substituted by crops. Area excluded (not able to be changed) from the modelling represents 12%. For

the initial situation (summer), multiannual sown pastures were the main cover occupying 44% of the area, followed by annual crops with 37% (Fig. 2a). With this land use configuration, mean productivity was 5.4 Mg DM.ha^{-1} and mean phosphorus exportation was 1.75 kg P. ha^{-1}. Resulting land use planning suggests an increase in multiannual pastures opposed to a decrease in annual crops. For the last summer of the planning horizon (fig. 2b) mean phosphorus exportation decreased to 1.57 kg P. ha^{-1}.

The solution produced allocations that fulfill crop sequence constraints but do not fulfill the remaining constraints (parameters 4 and 5). Regarding productivity, compliance was 68% with mean deviation equal to 425 kg/ha, below the allowable minimum for each season. Despite this, annual minimum set was always reached. Regarding number of uses, compliance was 41% with mean deviation equal to 2 uses above the maximum allowable.

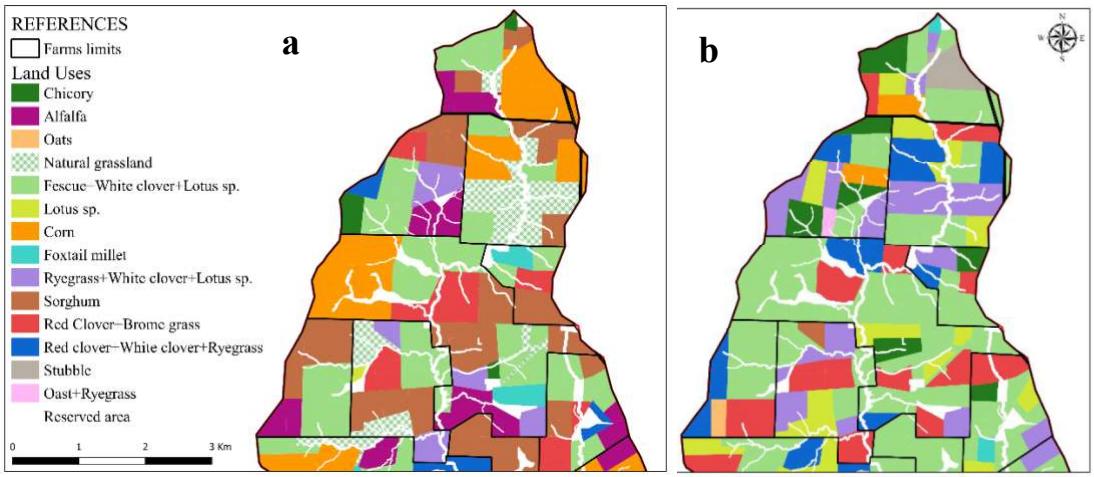

Figure 2. Part of the basin view for a) first summer (initial situation) and b) last summer in the planning horizon.

4 – Conclusions

The tool considers production needs at the level of individual farms as well as larger scale environmental objectives. This can contribute to the design of land use spatial distribution in production systems and provide information for the generation of public policies. The utilization of other decision units using smaller pixels instead of paddocks, could improve the optimization results.

References

DINAMA-JICA. (2011). Proyecto sobre control de contaminación y calidad de agua en la cuenca del Río Santa Lucía. Informe final del proyecto. Montevideo: DINAMA.

Delgado S. (2017). Planes para la Producción Lechera Sostenible. Anuario OPYPA. 291-296

Failde, A., Lanzilotta, B., Perdomo, C., Bidegain, M. P., & Rosas, F. (2015). Instrumentos fiscales para el control y la reducción de la contaminación en cursos de agua. http://www.cef.org.uy/images/Informes/Informe%20CalidadAgua_aPublicar.pdf

Rodríguez-Gallego, L., Cabrera, A. B. C., Kruk, C. Nin, M. & Mauttone, A. (2019). Establishing limits to agriculture and afforestation: A GIS based multi-objective approach to prevent algal blooms in a coastal lagoon. Journal of Dynamics & Games, 6(2), 159-17