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Nutrient Concentrations in a Pampasic First Order Stream with Different Land Uses in the Surrounding Plots (Buenos Aires, Argentina)

Hernán Mugni · Ariel Paracampo · Carlos Bonetto

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Abstract The objective of this study was to assess the effect of land use on nutrient concentrations in a Pampasic stream. Soluble reactive phosphorus (SRP) concentrations in the stream were higher at a site surrounded by fertilized double-cropped wheat/soybeans than at unfertilized soybeans plots. Nitrate and SRP concentrations in the stream were lower at sites surrounded by soybeans than livestock. It is suggested that crop fertilization and cattle manure increased nutrients loads released to the stream. It is suggested that preservation and restoration of riparian habitats may benefit water quality by decreasing nutrient loads.

Keywords Phosphorus · Nitrogen · Land use

The world's ecosystems are increasingly under pressure from various anthropogenic activities. Agriculture is essential for sustaining the human population, but also disrupts ecosystem functioning (Galic et al. 2012). Intensive agricultural practices are often blamed of nutrient loss to water bodies (Jarvie et al. 2010). Phosphorus and nitrogen enrichment is a problem of worldwide significance, leading to deterioration of water quality and eutrophication. Nutrient effects may be larger in first order streams where agricultural practices are adjacent to watercourses. Research over the last decade has identified agriculture as the land-use practice most associated with nutrient losses at field and farm scales (Jarvie et al. 2010). Dowd et al. (2008) suggest that pollution from non-point sources now constitutes the number one pathway, with agriculture being the single largest contributor. Moreover, Hooda et al. (2000) indicate that the increased world demand for food caused an increasing use of fertilizers and enhanced the risk of nutrient losses through leaching and runoff.

The "Pampa" is the main food production area of Argentina; it is an extensive plain with fertile soils and mild climate originally covered by grasslands. Traditionally farmers employed a mixed system of livestock and wheat/corn production. Soybeans were not traditional, until 1996, when the genetically modified soybeans resistant to glyphosate were introduced into the Argentine market. In recent decades soybeans cultivation has steadily increased along with the no-till management practice. This practice involves the seeding in a small furrow with the soil surface remaining largely undisturbed. Fertilizers are simultaneously applied in the same furrow. The no-till technique has long been recommended to reduce soil erosion. However, it became an increasingly common practice in concert with the cropping of soybeans plants resistant to glyphosate. Currently, soybeans account for approximately half of the total harvest and cultivated area in Argentina (50 million tons and 15 million ha, respectively; MAGyP 2010). Argentina is the world's third largest transgenic soybeans producer following the USA and Brazil. Wheat and soybeans varieties with a short growing period allow two harvests per year, with wheat followed by soybeans (Mugni 2009). Livestock acreage has been reduced and production has intensified, with increasing cattle densities. Fertilizer application during crop production has also increased, from 0.4 to 3.5 million tons from the early 90s to 2007 (CIAFA 2013). A 3 year rotation system is more and more common practice: soybeans are grown the first year, followed by a double wheat/soybeans crop the second year, and corn the

H. Mugni (✉) · A. Paracampo · C. Bonetto
Instituto de Limnología "Dr. Raúl. A. Ringuelet", ILPLA (CONICET-CCT La Plata)–UNLP, Boulevard 120 Y 62, 1900 La Plata, Buenos Aires, Argentina
e-mail: hemu@netverk.com.ar; mugni@ilpla.edu.ar

third. Often soybeans are not fertilized. It is assumed that the residual effect of wheat and corn fertilization enables a satisfactory soybeans harvest (Mugni 2009). Moreover, corn is assumed to improve the organic matter content of the soil.

It is hypothesized that nutrient concentrations in the regional streams strongly depend on the main crops and livestock soil use in their basins, and that the one important effect of agricultural intensification is the nutrient enrichment of surface waters because of enhanced fertilization. Therefore, present agricultural trends may represent a risk for environmental sustainability because nutrient enrichment might trigger eutrophication. This study assessed nutrient concentrations in a typical first order Pampasic stream located within a farm in which intensive management practices were implemented. The study compares nutrient concentrations at two sites throughout two successive growing periods with different cropping systems and livestock in the surrounding plots.

Materials and Methods

A first order Pampasic stream located on a farm in the main soybeans production area of Argentina, 7 km away from Arrecifes city (34°36′S, 58°30′W) and 150 km north-west of Buenos Aires city, was studied throughout two successive growing periods. The stream originated on a large farm; in a small depressed area that in rainy periods forms a small wetland. The farm is divided in plots where livestock and crops alternate. Two sampling sites were established, site 1 was located in the plot (119 ha) containing the stream's source (Fig. 1) and site 2 was located about 200 m downstream in the adjacent 122 ha plot. Two successive growing periods with different land use in each plot were assessed. During the first growing period, 4 samplings were performed during base flow conditions and 6 samples were taken after rain events, because nutrients concentrations were expected to change with stream discharge (Mugni 2009). During the second growing period 5 samples were taken during base flow conditions and 2 after rain events.

Although nutrient concentrations in the upstream site represent a baseline for the downstream site, it was tested whether nutrient concentration might differ between sites in response to nutrient loads from each surrounding plot. During base flow conditions, the stream discharge was low, in the range of 8–20 L/s, increasing to 230 L/s during heavy precipitation (Jergentz et al. 2005).

The mean slope between the sites was 1.5 %. The riparian vegetation was 1–2 m wide in the plot where the stream starts and gradually increases in the following plot. The climate in the region has an annual mean rainfall of 1,000 mm and mean temperatures range from 10°C in winter to 24°C in summer (Mugni 2009).

Regional soils belong to the Argiudol type, characterized by a surface A horizon (30 cm deep) with silty–clay grain size (52 %–64 % silt and 26 %–34 % clay) and 4.5 % organic matter, followed by a B horizon (80–100 cm deep), with 50 %–60 % clay (Mugni 2009).

Dissolved oxygen, pH and conductivity were measured in situ with an YSI 51B recorder, an Orion 250A pH meter and a Hanna 8733 conductivity meter, respectively.

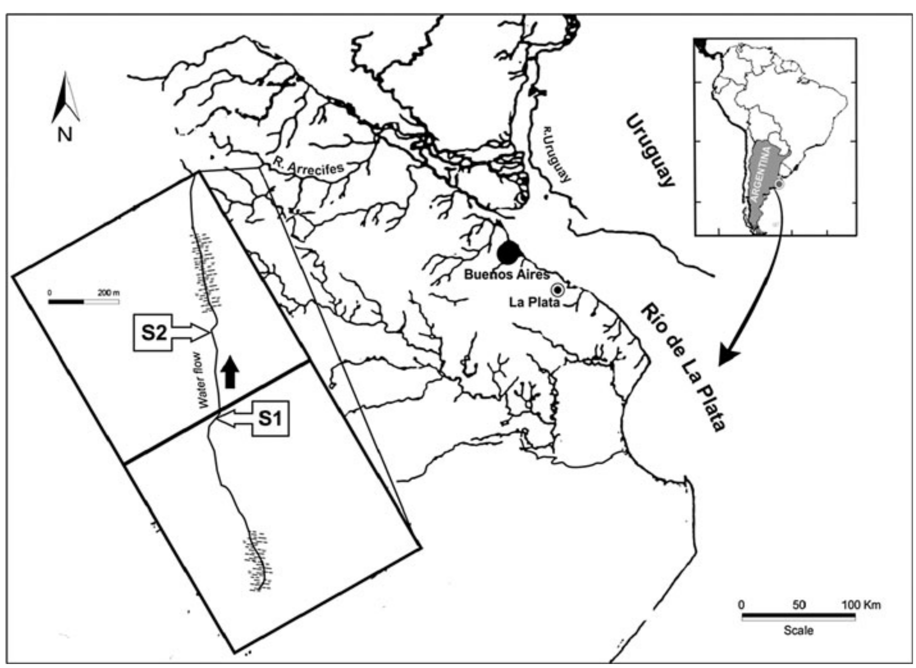

Fig. 1 First-order stream location and sampling sites "S1" and "S2"

Collected water samples were immediately filtered through Whatman GF/C filters and transported to the laboratory in amber glass bottles kept in coolers and covered with ice. Temperature within the coolers remained at about 4°C. Dissolved nutrients were determined in the filtrate. Soluble reactive phosphorus, SRP (molybdate-ascorbic), NO_3^- (Cd reduction followed by diazotation); and NH_4^+ (indophenol blue), were determined following American Public Health Association (1998).

Passive sampling devices were installed to sample stream water during flood-induced peak water level. Half liter bottles with two 5 mm diameter holes in the lid were mounted on sticks, with the opening about 15 cm higher than the steady state water surface (Schulz 2001). After floods produced by heavy rains, the filled bottles were recovered and the water was analyzed.

For each site, concentrations in each year were compared using a *t* test for independent samples. For each year, differences in nutrient concentration between sites were compared using a *t* test for dependent samples. In cases where the data did not meet the assumption of normality, differences were tested with the non-parametric Mann–Whitney U and Wilcoxon signed ranks test, analogous to the *t* test for independent and dependent samples, respectively.

Results and Discussion

Oxygen concentrations ranged between 4.5 and 15.0 mg/L. The minimum was measured in summer (January 10, 2003) and represented 60 % oxygen saturation (27°C). Water pH and conductivity ranged between 7.5 and 8.3 and 268–715 µS/cm, respectively.

Mean nutrient concentrations at different sites and growing seasons are summarized in Table 1. During the 2002/2003 growing period, soybeans without fertilization were grown in the upstream plot, where the stream starts (site 1, Fig. 1). The downstream plot remained with cattle on a natural, unfertilized pasture (site 2, Fig. 1). Mean cattle density was about 1 cow per hectare, a comparatively high density for an unfertilized pasture.

The overall mean SRP concentration in the stream, including base and flood flows, was significantly lower within the soybeans plot (144 µg/L) than within the downstream livestock plot 242 µg/L ($t = 5.42$; $p < 0.001$). Mean nitrate concentration within the soybeans plot (381 µg/L) was significantly lower than that within the livestock plot 1,765 µg N/L ($z = 2.80$; $p = 0.005$). Nitrate concentrations at site 1 were low in the first samplings, in November 2002, ranging from 57 to 71 µg N/L. Rains of low intensity (6–12 mm) occurred the week prior to each sampling. By contrast, concentrations peaked at 1,993 µg N/L after a 50 mm rain event on December 17. On that occasion nitrate concentration in flood flows (2,684 µg N/L) was higher than in stream water after the flood peak.

During the 2003–2004 growing period, wheat followed by soybeans were grown in the upstream plot and soybeans in the downstream plot. Wheat was fertilized at the time of sowing, in late May, with 120 kg/ha of di-ammonium phosphate and 135 kg/ha of urea. The downstream soybeans plot was not fertilized. The mean SRP concentration in the fertilized wheat/soybeans plot (456 µg/L) was significantly higher than in the same plot the previous year 144 µg/L ($t = 5.67$; $p = 0.001$), when unfertilized soybeans were grown. SRP concentrations in the fertilized wheat/soybeans plot was not significantly different than in the downstream soybeans plot 314 µg/L ($t = 0.07$; $p = 0.95$). Nitrate concentrations were high in both sites during the first sampling after wheat fertilization (1,300 µg N/L), and decreased in the following samplings. The mean nitrate concentration in the unfertilized soybeans plot (598 µg N/L) during the 2003–2004 growing period was significantly lower than in the same site the previous year, when the plot still had cattle 1,765 µg N/L ($t = 3.39$; $p = 0.004$). Ammonium was always a minor component of the N pool; its concentrations did not show significant differences between sites or growing periods. At the prevailing pH and temperature, the estimated un-ionized ammonia concentrations were far below threshold limits for toxicity to freshwater fauna (19 µg/L of un-ionized ammonia; CCME 2010).

Our results suggest that nutrient concentrations in the stream were influenced by land use in the surrounding plots. Crop fertilization represented a source of nutrients since fertilized wheat/soybeans resulted in higher SRP concentrations in the stream than unfertilized soybeans

Table 1 Nutrient concentration (mean ± standard deviation) for each season and crop in the first-order stream adjacent to plots with different land uses

Season	N	Site	Crops	Cond. (µS/cm)	pH	SRP (µg/L)	N-NH_4^+ (µg/L)	N-NO_3^- (µg/L)
2002–2003	10	1	Soybeans	467 ± 125	8.3 ± 0.4	144 ± 50	27 ± 18	381 ± 592
	10	2	Cattle	546 ± 62	7.8 ± 0.5	242 ± 72	31 ± 17	1,765 ± 899
2003–2004	7	1	Wheat/soybeans	329 ± 150	8.1 ± 0.2	456 ± 155	22 ± 8	159 ± 194
	7	2	Soybeans	560 ± 85	7.5 ± 0.1	314 ± 146	41 ± 21	598 ± 399

grown the previous year. In the present study, nitrate concentrations in the stream were lower when the surrounding land use was soybeans production than when it was livestock production. Nutrient loads from livestock likely depend on management practices. Extensive rangeland with lower cow densities resulted in lower nitrate concentrations in similar first order streams, with mean values of around 300 μg N/L (Mugni 2009). In the farm under study, the stream was the only water source for cattle. The cattle moved freely within the plot and gathered along the stream banks for drinking. Livestock trampling deteriorated the riparian vegetation. Cattle manure accumulated in the riparian fringe represents a source of nutrients to the stream. In the subsequent growing period, soybeans were grown, which is usually not fertilized because it is a symbiotic N fixer. N fixation accounted for 53 % of the total N in the soybeans biomass, ranging between 13 %–73 %, in 33 commercial plots of Australia (Unkovich and Pate 2000). A variable but significant amount of N is taken from the soil, likely reducing soil nitrate losses through runoff.

Our results suggest that agricultural intensification can cause nutrient enrichment of surface waters derived from increased fertilizer applications and cattle densities. Soybeans do not seem to be the main nutrient source because it is usually not fertilized. Intensive soybeans cultivation apparently attenuates the effect of the accompanying crops and livestock.

In this context, Hart et al. (2004) studied the losses of nutrients following fertilization of grassland during runoff: P concentrations were 5 times higher in fertilized than unfertilized plots, amounting 3.3 mg/L of dissolved and 2.8 mg/L of particulate P in conjunction with rains that occurred within a few days after application.

Jiao et al. (2011) pointed out the effect of different cropping systems on P losses through runoff. Wheat/soybeans double cropping contributed less P than wheat/fallow, wheat/cotton and wheat/corn. Reduced runoff P loads were attributed to the high crop canopy cover reducing soil erosion.

With the purpose to compare the present study's results with literature data, the nutrient concentration in streams receiving exclusively non-point sources of pollution is summarized in Table 2. All quoted references reported that streams draining areas of intense row cropping typically contained higher nitrate concentrations than those draining pastures or rangeland, while streams draining forested areas had the lowest nitrate concentrations. All reported publications concluded that agriculture was the main nitrate source to the streams. Boyer and Pasquarell (1995) reported a linear relation between mean nitrate concentration in Appalachian streams (USA) and the percentage of the associated basin that was occupied by agricultural land. Nitrate concentrations in the Pampasic first-order stream were modest when compared to reported figures from intensively cultivated basins in Europe and North America. Since soybeans, the dominant crop, is usually not fertilized with N in Argentina, comparatively low nitrate concentrations appear to be the result of lower fertilization loads.

The mean SRP concentrations in our first order stream when unfertilized soybeans were grown (Table 1) were

Table 2 Mean nitrate (μg N/L) and SRP (μg/L) in streams draining basins with different land use

Basin/region	Land use	Nitrate (μg/L)	SRP (μg/L)	Source
Potomac, USA	Agriculture	5,000	14	Miller et al. (1997)
	Forest	400	<10	
Appalachian, USA	Agriculture	15,000	–	Boyer and Pasquarell (1995)
	Forest	400	–	
North Carolina, USA	Agriculture	5,600	680	Stone et al. (1995)
	Forest	1,100	120	
Midwestern, USA	Agriculture	3,600	36	Johnson et al. (1997)
	<50 % Agric.	900	37	
Central Nebraska, USA	Cropland	5,000	<200	Boyd (1996)
	Rangeland	600	<150	
Seine, France	Agriculture	5,000	14	Meybeck (1998)
	Forest	500	14	
Lake District, England	Pasture	400	4	Lawlor et al. (1998)
Taw, England	Pasture, low intensity sheep rearing	2,000	<7	Jarvie et al. (2008)
	Agric./intensive cattle farming	9,000	55	
Girou, France	Agriculture	5,700	33	Probst (1985)
Ohebach, Germany	Agriculture	5,900	29	Schulz and Liess (1999)
Pampasic stream	Agriculture	400	305	Present study

higher than in most reported studies. The rich soils developed over the loessic sediments of the Argentine Pampa (Garcia et al. 2006) seem to be the cause of the comparatively high SRP concentrations in the regional streams. Fertilization in the adjacent plots increased the SRP concentration in the stream. Overall, the present study underpins the importance of agricultural intensification in the nutrient enrichment of surface waters. Since water quality preservation is one of the major environmental challenges, improved management practices such as adjusting fertilization timing seem to be needed to reduce nutrient loads to streams. Moreover, Mugni et al. (2005) observed that nitrate concentrations were lower in streams containing extensive riparian vegetation than in those where the riparian vegetation was removed. Riparian habitat protection and restoration may help to reduce stream nutrient concentrations.

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