Received: 19 November 2019 | Revised: 3 September 2020 | Accepted: 18 September 2020
DOI: 10.1002/ldr.3777

RESEARCH ARTICLE

WILEY

Impacts of soil use and management on water quality in agricultural watersheds in Southern Brazil

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Funding information
Conselho Nacional de Desenvolvimento Científico e Tecnológico; Empresa Brasileira de Pesquisa Agropecuária; Itaipu Binacional

Abstract

Worldwide, agriculture is considered one of the main activities that influence water quality. The objective of this work was to evaluate the influence of soil use and management on water quality at the small watershed scale, in Southern Brazil. One watershed is characterized by production of annual crop seeds under no-tillage (zero tillage), with crop rotation and with terraces (Sarandi watershed—SW), while the other is characterized by production of grains in the summer and pasture with grazing in the winter, under no-tillage, without crop rotation and without terraces (Coxilha watershed—CW). Flow and climatic data were measured during 2 years. Water samples were manually taken at precipitation events and base flow over 1 year for laboratory analysis. During events of high volume, most of the rainfall was converted to base flow in SW, while in CW, most of the rainfall was transformed into overland flow. Overall, higher concentrations and losses of sediments and nutrients occurred in the CW, mainly during precipitation events in the winter crops season. Of the total nitrogen concentration in water, approximately 3% was ammonium-N and 58% was nitrate-N, on average, in both watersheds. For total phosphorus concentration in water, more than 75% was particulate in both watersheds, however, the bioavailable phosphorus accounted for 70% of the total phosphorus in the SW and for 35% in the CW. The higher concentration of bioavailable phosphorus in the SW indicates a short-term pollution potential, but in both watersheds, the water quality was impaired by the high concentrations of total phosphorus. In general, even with no-tillage, the results highlight the importance of best management practices as terracing, riparian vegetation, crop rotation, better crop systems and fertilizer management to avoid degradation of water resources.

KEYWORDS
best management practices, catchment, crop production, no-tillage, water conservation

1 | INTRODUCTION

The benefits of no-tillage systems regarding water, soil and nutrient losses have already been listed by several authors (Gassman et al., 2006; Niu et al., 2015; Shi, Ai, Fang, & Zhu, 2012; Silva & De Maria, 2011). Thirty-three million hectares is the total Brazilian no-tillage area and the Southern region, representing the subtropical climate, accounts for 36% (12 million ha) (IBGE, 2017). However, it is known that the no-tillage systems widely used by farmers in Brazil do not apply all the practices recommended by conservation agriculture, such as no-tillage with crop rotation, high soil cover with plant residue and surface runoff control structures (Merten, Araújo, Biscaia, Barbosa, & Conte, 2015). Deuschle, Minella, Hörbe, Londero, and Schneider (2019), studied the erosion and hydrological response of crop rotation intensification in no-tillage on a Nitisol with a high clay content (>50%) on agricultural hillslopes (length of 90 m and slope of 9%) in Southern Brazil. They observed that no-tillage without crop rotation and without terraces was not enough to control runoff and soil erosion, even during low-intensity events. In that study, crop rotation intensification with winter cover crops (*Avena strigosa*, *Vicia sativa* and *Raphanus sativus*) providing high soil cover with plant residue reduced 84% of soil loss but only 18% of runoff, indicating that complementary practices such as terraces are necessary to control runoff even in no-tillage under crop rotation intensification. Londero et al. (2018) found that the adoption of the broad-based retention terraces in a zero-order watershed (2.4 ha) with no-tillage in Southern Brazil reduced runoff and sediment yield by almost 78 and 65%, respectively.

The surface runoff generated in agricultural fields transports water, soil and associated pollutants, compromising the quality of water resources (Albuquerque et al., 2016; Ding et al., 2016; Kay, Edwards, & Foulger, 2009). The risk of transporting pollutants to water courses is related to rainfall characteristics such as intensity, volume, duration and interval between events, soil attributes such as texture and structure, and topographic features such as length and degree of slope; however it is potentiated by inadequate use and management of soil, crops and agrochemicals and by the high connectivity to agricultural fields with absence of riparian vegetation (Bortolozo et al., 2015; Deuschle et al., 2019; Londero et al., 2018; Lourençato et al., 2015; Minella, Walling, & Merten, 2014; Ramos et al., 2014; Ribeiro et al., 2014; Shi et al., 2012).

Most studies of water, sediment and nutrient losses in Brazil with soil tillage and management systems have been done in small plots with simulated or natural rainfall (Bertol et al., 2011; Bertol, Rizzi, Bertol, & Roloff, 2007; Denardin, Kochhann, Faganello, Sattler, & Manhago, 2008; Gebler, Bertol, Ramos, Louzada, & Miquelluti, 2012; Guadagnin, Bertol, Cassol, & Amaral, 2005; Silva & De Maria, 2011). Studies at greater scale are needed and field experiments with large plots in Brazil have been increased recently (Coblinski et al., 2019; Deuschle et al., 2019; Londero et al., 2018; Merten et al., 2015; Ramos et al., 2014). Losses of soil, water and agrochemicals in a watershed cannot be estimated by the sum of results from individual fields, even from large plots (Ding et al., 2016; Raclot et al., 2009; van de Giesen, Stomph, & de Ridder, 2005) so studies at watershed scale following the real field condition are essential to assess water quality (Capoane, Tiecher, Schaefer, Ciotti, & dos Santos, 2015; Gafur, Jensen, Borggaard, & Petersen, 2003; Martínez-Casasnovas, Ramos, & Benites, 2016; Niu et al., 2015; Nu-Fang, Zhi-Hua, Lu, & Cheng, 2011; Shi et al., 2012; Shore et al., 2014; Shore et al., 2017) as well as to calibrate empirical mathematical models (Durães, de Mello, & Naghettini, 2011; Raclot et al., 2009; Shi et al., 2012; Tong & Chen, 2002; van de Giesen et al., 2005). The hydrology dynamics on watershed scale is different from small or even large plots mainly due to the variability in soil characteristics, topography and rainfall (van de Giesen et al., 2005). So, to better understand the non-point source pollution and to recommend best management practices, more studies need to be carried out at agricultural small watersheds following the system conducted by farmers.

Considering that farmers adopt different practices in their agricultural fields, this study aimed to evaluate the water quality of two small agricultural watersheds with different systems of soil use and management. One watershed is characterized by continuous cropping system in no-tillage with crop rotation and with terrace and the other an integrated crop-livestock system in no-tillage without crop rotation and without terrace. The hypothesis of our study was that even with no-tillage, best management practices, such as crop rotation, high soil cover by plant residue, terraces and riparian vegetation reduces the losses of water, sediments and nutrients and, consequently, contribute to better water quality. Studies at watershed scale with the real field condition, following the whole system conducted by the farmers, are needed for practical recommendation in order to preserve the environmental quality.

2 | MATERIAL AND METHODS

2.1 | Experimental sites

The study was carried out in two small watersheds located in the Medium Plateau Region of Rio Grande do Sul, Sarandi and Coxilha, with the coordinates 27°55′33.99″S and 52°47′26.39″W, and 28°11′47.86″S and 52°20′31.47″W, respectively (Figure 1). These watersheds are located in Southern Brazil, under a subtropical Cfa climate which has warm summers and cold winters with frost, and rainfall well distributed throughout the year (Alvares, Stape, Sentelhas, De Moraes Gonçalves, & Sparovek, 2013). The historic average annual rainfall is 1,958 mm for Sarandi watershed (SW) and 1,923 mm for Coxilha watershed (CW) (IRGA, 2020). The average annual rainfall erosivity estimated by multivariate models, according to Mello, Viola, Beskow, and Norton (2013) reaches 9,213 MJ mm ha^{-1} yr^{-1} for SW and 8,696 MJ mm ha^{-1} yr^{-1} for CW.

These watersheds are constituted by one first-order stream (headwater drainage) and have different use and management. The SW, 13.3 ha, produces commercial maize (*Zea mays*) and soybean (*Glycine max*) seeds in the summer, and cereals such as wheat (*Triticum aestivum*) and oats (*Avena sativa* and *A. strigosa*) in the winter, under continuous no-tillage and crop rotation with terracing (level type terraces). The CW, 19.1 ha, produces soybean grains in the summer and oat pasture in the winter, with animals grazing under no-tillage (crop–livestock integrated system) without crop rotation and without terracing. The management of fertilization is shown in Table 1.

Both watersheds have riparian vegetation; however, it is inadequate in area and/or type of vegetation according to Brazilian environmental legislation (Brasil, 2012). In SW, 21% of the riparian vegetation (30 m each side of the stream) defined by Brazilian Law (Brasil, 2012) is constituted by spontaneous grass (forage grasses and native grasses) and 79% is annual crops. In CW, 49% of the riparian vegetation is constituted by native species (38% forest and 11% grasses) and 51% by annual crops.

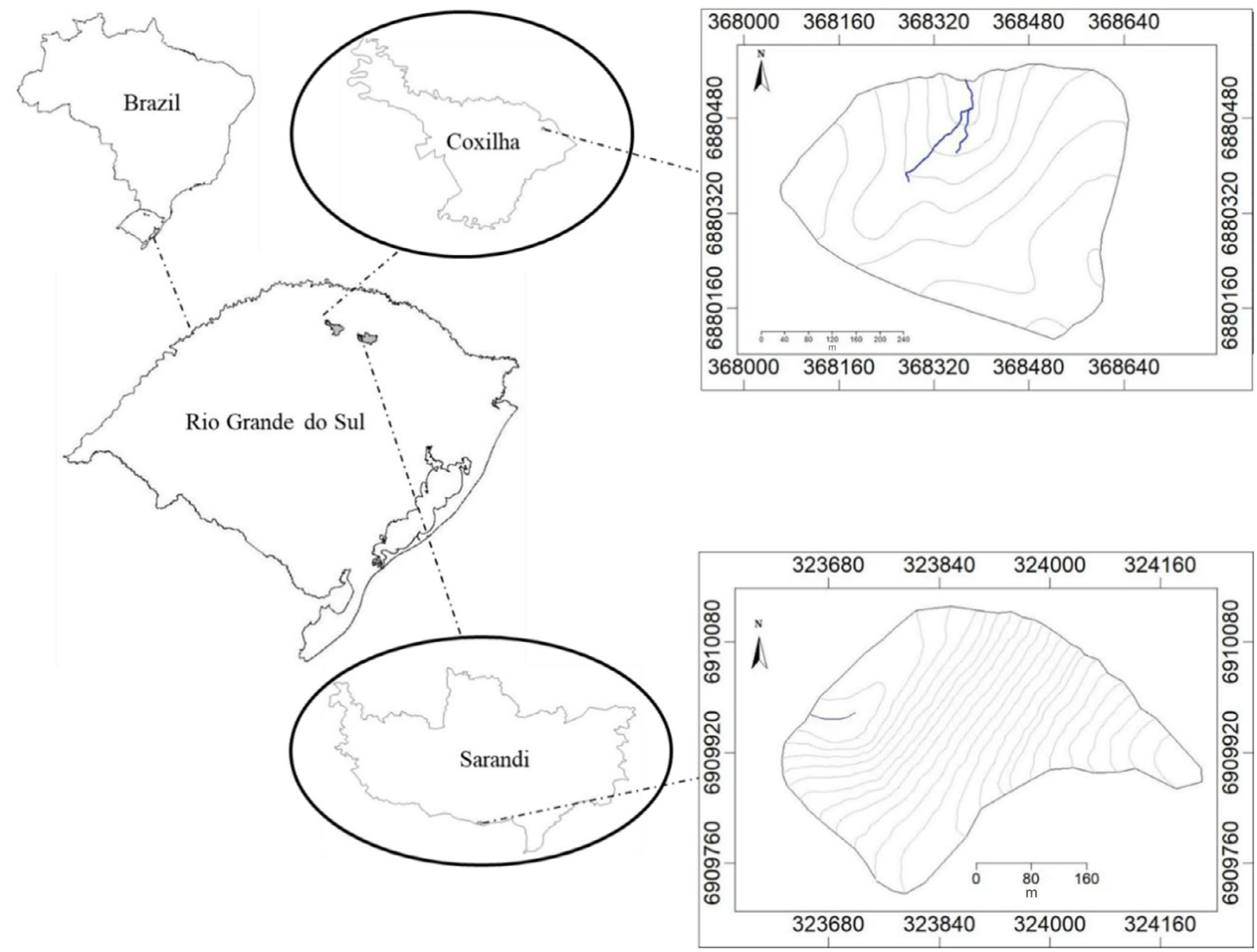

FIGURE 1 Localization and topographic characterization of the watersheds. CW, Coxilha watershed (upper); SW, Sarandi watershed (lower) [Colour figure can be viewed at wileyonlinelibrary.com]

The soil (Table 2) of both watersheds is classified as Oxisol according to US Soil Taxonomy (Soil Survey Staff, 1999), corresponding to Dystrophic Red Latosol (EMATER/RS—Ascar, 2007) under Brazilian Soil Taxonomy (EMBRAPA, 2013).

Topographic indices (Table 3) were determined using SAGA 2.2.2 (System for Automated Geoscientific Analyses) according to Conrad et al. (2015), with equidistant level curves of 2 m. The data used were based on satellite images (Pleiades 1 m; Phased Array L-band Synthetic Aperture Radar (PALSAR) on the ALOS satellite 12.5 m and Shuttle Radar Topography Mission (SRTM) 30 m); aerial images (Vexcel UltraCam D digital camera); and topographic surveys carried out in the watersheds with Global Positioning System receivers (GPS Garmin eTrex Vista with horizontal accuracy of better than 3 m). The slope was similar, on average 9.7% in SW and 8.7% in CW (Table 3). The length and slope represent the LS factor, which in turn determines the erosion potential (Minella, Merten, & Ruhoff, 2010). According to the mean values obtained for LS (Table 3), the two watersheds have low erosive potential. The MRVBF index (Multiresolution Index of Valley Bottom Flatness), which defines areas of deposition in a landscape (Gallant & Dowling, 2003), identifies deposition areas in both watersheds (the mean value was higher than 0.5) (Table 3). The profile and plan curvature of the surface influence the water flow (Minella & Merten, 2012), and both watersheds are classified as divergent convex (Table 3) since the mean in both curvatures is positive (Valeriano, 2008; Valeriano & Carvalho, 2003).

2.2 | Flow monitoring and climate data collection

Downstream flow at each watershed was continuously monitored over 2 years (October 2015–October 2017) with hydrosedimentological stations (radar water level sensor [Campbell Scientific, model CS475] connected to a measurement and control datalogger [Campbell Scientific, model CR1000]), providing data of the water level every 5 min.

The flow was obtained by Equation (1) for SW (triangular-type masonry spillway) and by Equation (2) for CW (rectangular-type masonry spillway), according to Baptista, Coelho, Cerilo, and Mascarenhas (2003):

TABLE 1 Fertilization and days of seeding and harvesting of the crops in the watersheds

	Sarandi watershed				Coxilha watershed			
	Crop	Seeding	Fertilization (kg ha^{-1})	Harvest	Crop	Seeding	Fertilization (kg ha^{-1})	Harvest
Summer 2015/16	Soybean	11/16/15	12 kg of N (S)	03/29/16	Soybean	10/15/15	58 kg of K_2O (BS)	02/25/16
			69 kg of P_2O_5 (S)				12.5 of de N (S)	
			69 kg of K_2O (S)				75 kg of P_2O_5 (S)	
							25 kg of K_2O (S)	
Winter 2016	Oats	04/05/16	44 kg of N (S)	10/30/16	Oats	02/30/15	nd	nd
			120 kg of P_2O_5 (S)					
			80 kg of K_2O (S)					
			45 kg of N (C)					
Summer 2016/17	Maiz	11/06/16	85.3 kg of N (S)	05/03/17	Soybean	11/29/16	43.5 kg of K_2O (BS)	04/10/17
			174.6 kg of P_2O_5 (S)				6.6 kg of N (S)	
			128.5 kg of K_2O (S)				59.4 kg of P_2O_5 (S)	
			157.5 kg of N (C)				59.4 kg of K_2O (S)	
Winter 2017	Wheat	05/10/17	100 kg of N (C)	11/17/17	Oats	04/12/17	nd	nd

Abbreviations: BS, fertilization before seeding; C, fertilization in coverage; nd, without fertilization and without harvest with animal grazing; S, fertilization during seeding.

TABLE 2 Physical and chemical properties of the soils

Watershed	Depth cm	Clay	Silt + sand	pH water	P	K	C g dm^{-3}	Al	Ca	Mg	H + Al	CEC	V %
		-----%------			--mg dm^{-3}--			--mmol$_c$ dm^{-3}--			--mmol$_c$ dm^{-3}--		
Sarandi	0–5	42.3	57.7	5.5	39.7	272.3	25.8	4.0	58.0	22.9	56.4	144.2	60.9
	5–10	54.5	45.5	5.3	33.0	177.9	19.8	12.7	38.2	15.7	76.4	134.8	44.0
	10–20	58.5	41.5	5.1	12.0	158.5	16.1	17.4	30.0	12.0	81.1	127.1	37.3
	20–40	58.6	41.4	5.0	8.5	106.4	14.1	22.6	22.7	9.5	90.3	125.2	29.2
Coxilha	0–5	28.1	71.9	5.9	20.2	251.3	23.8	1.4	60.2	26.5	38.7	128.6	69.4
	5–10	33.7	66.3	5.5	21.5	137.3	16.3	5.7	48.4	18.6	53.7	124.2	57.7
	10–20	35.8	64.2	5.3	24.0	83.3	14.0	8.9	42.2	15.5	61.4	124.4	52.7
	20–40	41.2	58.8	5.3	4.4	56.9	12.5	14.9	32.7	13.6	76.8	124.6	40.5

Abbreviations: CEC, cation exchange capacity; V, base saturation.

$$Q = \frac{1}{n}\cdot\left(m\cdot y^2\right)\cdot\left(\frac{m\cdot y^2}{2\cdot y\cdot\sqrt{m^2+1}}\right)^{2/3}\cdot\sqrt{I}, \tag{1}$$

$$Q = \frac{1}{n}\cdot\left(B\cdot y\right)\cdot\left(\frac{B\cdot y}{B+2y}\right)^{2/3}\cdot\sqrt{I}, \tag{2}$$

Where: Q = flow, m^3 s^{-1}; n = channel roughness coefficient, s m$^{-1/3}$; m = inclination of the slope, m; y = height of the water over the spillway crest, m; I = channel slope, m m^{-1}; and B = base width, m.

For the channel roughness coefficient (n), a value of 0.013 was considered, since it is a fitted stone masonry wall conduits (Baptista et al., 2003). Channel slope values (I) were measured in the field: 0.005 m m^{-1} for SW and 0.009 m m^{-1} for CW. For the inclination of the slope (m), specifically for SW with triangular spillway, a value of 0.6 m was calculated.

To estimate the groundwater recharge from the discharge data sets, a method based on the recession-curve displacement was applied, through the daily flows and daily precipitation data sets. The discharge flow was classified as overland flow and base flow according to Barnes' method (Barnes, 1939); recession curves and coefficients were defined following the fundamentals of the Maillet exponential function (Equation (3)).

$$Q_t = Q_0 e^{-at}, \tag{3}$$

Where: Q_t = flow rate at time t, m^3 s^{-1}; Q_0 = the initial flow at the time of the hydrograph recession period, m^3 s^{-1}; e = base of the Napierian logarithm (exponential); a = coefficient of recession, s^{-1}; and t = time, days.

Precipitation data were continuously collected by an automatic rain gauge station (Hydrological Services America, model TB4) connected to a datalogger (Campbell Scientific, model CR1000), placed inside of the watersheds.

TABLE 3 Topographic indices of the watersheds

Topographic indices	Sarandi watershed (13.3 ha)			Coxilha watershed (19.1 ha)		
	Average	Minimum	Maximum	Average	Minimum	Maximum
Slope (%)	9.71	0.02	26.71	8.68	0.01	27.31
MRVBF index	0.71	0.00	4.95	0.69	0.00	4.07
LS factor	1.07	0.00	4.12	0.92	0.00	3.79
Plan curvature	0.00430	−9.02866	8.00000	0.00266	−10.22720	17.21721
Profile curvature	0.00017	−0.03074	0.02947	0.00038	−0.025450	0.089295

Note: Plan curvature (negative: convergent; positive: divergent, null: rectilinear); profile curvature (negative: concave; positive: convex, null: rectilinear); MRVBF (<0.5 erosion and >0.5 deposition); LS (0–4: low; 4–6: medium; 6–10: high erosion).

TABLE 4 Date of water sampling and precipitation volume in the sampling day and 1 and 2 days before sampling

Sarandi watershed					Coxilha watershed				
		Precipitation (mm)					Precipitation (mm)		
Samples	Date	0 day	1 day	2 days	Samples	Date	0 day	1 day	2 days
1	10/27/16$^{1\text{-}S}$	4.3	22.6	25.6	1	10/27/16$^{1\text{-}S}$	2.3	14.5	19.3
2	11/18/16$^{1\text{-}S}$	0.3	1.8	8.9	2	11/21/16$^{1\text{-}S}$	0.0	0.0	0.0
3	12/05/16$^{1\text{-}S}$	0.0	0.5	24.4	3	12/05/16$^{1\text{-}S}$	0.0	0.3	29.0
4	12/21/16$^{1\text{-}S}$	0.0	0.3	22.1	4	12/21/16$^{1\text{-}S}$	0.0	0.3	7.9
5	01/05/17$^{1\text{-}S}$	1.0	4.6	38.1	5	01/05/17$^{2\text{-}S}$	40.9	7.4	7.9
6	01/27/17$^{1\text{-}S}$	13.0	0.3	13.3	6	01/23/17$^{1\text{-}S}$	0.0	0.0	0.0
7	02/08/17$^{1\text{-}S}$	0.0	0.0	0.0	7	02/09/17$^{1\text{-}S}$	10.4	0.0	0.0
8	02/21/17$^{1\text{-}S}$	0.0	0.3	15.8	8	02/22/17$^{1\text{-}S}$	0.5	0.0	0.0
9	03/20/17$^{1\text{-}S}$	0.0	0.0	0.0	9	03/17/17$^{2\text{-}S}$	0.0	43.7	43.7
10	04/10/17$^{2\text{-}S}$	24.0	43.0	43.0	10	04/10/17$^{2\text{-}S}$	3.6	57.9	78.0
11	04/27/17$^{2\text{-}S}$	0.0	105.0	147.0	11	04/27/17$^{2\text{-}W}$	0.0	21.8	135.1
12	05/15/17$^{2\text{-}W}$	2.0	52.0	52.0	12	05/15/17$^{2\text{-}W}$	0.0	1.3	44.2
13	06/12/17$^{1\text{-}W}$	0.0	0.0	1.0	13	05/23/17$^{2\text{-}W}$	38.6	0.3	4.1
14	07/05/17$^{1\text{-}W}$	0.0	0.0	0.0	14	06/02/17$^{2\text{-}W}$	0.3	9.1	42.9
15	07/16/17$^{1\text{-}W}$	2.3	0.0	0.0	15	06/08/17$^{2\text{-}W}$	34.3	99.3	99.3
16	07/27/17$^{1\text{-}W}$	0.0	0.0	0.0	16	07/07/17$^{1\text{-}W}$	1.5	0.0	0.0
17	08/13/17$^{2\text{-}W}$	108.7	9.7	9.9	17	07/17/17$^{2\text{-}W}$	14.0	4.1	4.1
18	08/31/17$^{1\text{-}W}$	0.0	0.0	0.0	18	07/27/17$^{1\text{-}W}$	0.0	0.0	0.0
19	09/16/17$^{2\text{-}W}$	3.6	34.5	48.8	19	08/11/17$^{1\text{-}W}$	0.3	0.0	0.3
20	10/02/17$^{2\text{-}W}$	0.3	38.9	40.6	20	08/14/17$^{2\text{-}W}$	0.3	84.6	93.2
21	10/11/17$^{2\text{-}W}$	77.0	3.3	15.8	21	08/31/17$^{1\text{-}W}$	0.0	0.0	0.0
22	10/25/17$^{2\text{-}W}$	24.1	0.0	0.0	22	09/29/17$^{2\text{-}W}$	17.8	3.8	3.8
					23	10/06/17$^{2\text{-}W}$	17.5	0.0	0.0
					24	10/11/17$^{2\text{-}W}$	66.6	1.0	10.9
					25	10/25/17$^{2\text{-}W}$	10.4	0.0	0.0

Notes: ^{1} base flow; ^{2} precipitation events; ^{S} summer crop; ^{W} winter crop.

2.3 | Water sampling

Water was manually sampled at two points (upstream—P1 and downstream—P2) in 1-L plastic bottles, from October 2016 to October 2017, during precipitation events (rainfall) and on dry days (base flow). The base flow samples are those for which there were no precipitation events or there was very low precipitation, but no surface runoff generated on the day of collection and 2 days previous. Precipitation samples are those for which rainfall occurred during collection or before collection, in a volume sufficient to produce surface runoff.

In total, 22 samples were collected in SW and 25 in CW (SW: 14 for base flow, 8 in precipitation events, 11 in the summer crop, 11 in the winter crop; CW: 11 for base flow, 14 in precipitation events, 10 in the summer crop, 15 in the winter crop) (Table 4). Crop cycles (summer and winter) were separated according to the sowing and harvest dates of the different crops for each watershed. Of the collections made for the summer crop in SW, 9 were for base flow and 2 for precipitation events, and in CW, 7 were for base flow and 3 for precipitation events. On the other hand, for the samples collected in the winter crop, 5 were for base flow and 6 for precipitation events in SW, and 4 for base flow and 11 for precipitation events in CW.

2.4 | Water analysis

Each water sample was analyzed in triplicate for all parameters. For total solids (sediments; TS), an aliquot (at least 50 ml) was dried in an oven at 105°C (APHA, 1995). pH and electrical conductivity were obtained through multiparameter apparatus (Hanna), and turbidity was determined via turbidimeter (Quimis). Nitrogen (N) and phosphorus (P) were determined as: soluble nitrate (NO_3-N), soluble ammonium (NH_4-N), particulate nitrogen (PN), total nitrogen (TN), soluble phosphorus (SP), particulate phosphorus (PP), bioavailable phosphorus (BP), bioavailable particulate phosphorus (BPP), non-bioavailable particulate phosphorus (NBPP) and total phosphorus (TP). For nutrients, the separation of the soluble fraction was performed by filtration using a 0.45 μm filter.

The methodology used to obtain NO_3-N was ultraviolet spectrometry with Zn reduction (Heinzmann, Miyazawa, & Pavan, 1984; Norman & Stucki, 1981); that used for NH_4-N was phenate (APHA, 1995). They were determined by a spectrophotometer at 210 nm for NO_3-N and 640 nm for NH_4-N. To obtain TN, Kjeldahl digestion (APHA, 1995) in an unfiltered sample was performed; the detection methodology for Kjeldahl N was the same as for soluble NH_4-N. The Kjeldahl digestion method does not include nitrate, so TN was obtained by the sum of Kjeldahl N and soluble NO_3-N (Sharpley & Menzel, 1987). The PN was obtained by the difference between TN and soluble N (NH_4-N + NO_3-N).

SP was determined in the filtrate in a 0.45 μm pore size by inductively coupled plasma optical emission spectrometry (ICP-OES VARIAN 720-ES). TP was obtained in the unfiltered sample by acidic digestion in a microwave oven (model MARS 6; CEM®) according to USEPA 3015a (USEPA, 2007), and subsequent determination by ICP-OES. The particulate P was obtained by the difference between TP and SP. BP was determined in an unfiltered sample by the iron oxide impregnated filter membrane method, according to Sharpley (1993) and adapted by Myers and Pierzynski (2000), and its concentration was determined by ICP-OES. BPP was obtained by the difference between BP and SP, and the NBPP through subtraction of BPP from PP.

Total organic carbon (TOC) was determined using the unheated dichromate oxidation method (Boyd & Tucker, 1992; Tedesco, Gianello, Bissani, Bohnen, & Volkweiss, 1995).

2.5 | Determination of annual water yield and sediment and nutrient losses

The annual water yield was determined by Equation (4).

$$PA = \frac{\sum Q}{A}, \quad (4)$$

Where: PA = annual water yield, $m^3\ ha^{-1}\ yr^{-1}$; Q = daily water flow, $m^3\ d^{-1}$; and A = area of the watershed, ha.

Annual loss of sediments and nutrients was determined by Equation (5), adapted from Yang, Zhang, and Zhao (2007).

$$TP = \frac{\sum_{i=1}^{n} kCiD}{1{,}000A}, \quad (5)$$

Where: TP = annual loss, $kg\ ha^{-1}\ yr^{-1}$; n = number of collections; k = interval between one collection and another, days; Ci = concentration of sediments or nutrients of a given sample, $mg\ L^{-1}$; D = mean stream flow of the interval between one collection and another, $m^3\ d^{-1}$; 1,000 = conversion factor; and A = area of contribution of the watershed, ha.

It is important to point out that the annual losses of sediment and nutrients in our study according to Equation (5) were calculated considering the concentration data from samples collected at intervals of approximately 15 days, in base flow and precipitation events, but not in all events. Also, only one sample was collected in each precipitation event, so annual loss of sediment and nutrients is a rough estimative and not a truly loss.

Annual loss of sediments and nutrients also were estimated using Load Estimator model (LOADEST); (Runkel, Crawford, & Cohn, 2004). This program uses a time-series of stream flow and concentration data and provides a regression model for the estimation of loss. For the LOADEST, the inputs were the mean stream flow daily and the concentration from samples collected at intervals of approximately 15 days, in base flow and precipitation events, so a total of 22 data points for SW and 25 for CW.

2.6 | Statistical analysis

The data were submitted to descriptive analysis, and multivariate analysis with principal components analysis using CANOCO statistical software (Ter Braak & Smilaue, 2012).

3 | RESULTS

3.1 | Flow and water yield

Precipitation during the study period (2 years), 4,944 mm in SW and 4,691 mm in CW, was similar and well distributed (Figure 2); however, there were events of high precipitation, with values greater than 100 mm, which resulted in higher flows, mainly in CW. The highest rain volume was 119 mm at SW (Figure 2a) and 131 mm at CW (Figure 2b). The highest event at SW produced 0.0106 m^3 s^{-1} flow, which corresponds to 6.87 mm of water yield, with 77% (5.32 mm) as base flow (Figure 2a); CW produced 0.0216 m^3 s^{-1} flow, which corresponds to 9.77 mm of water yield, with 48% (4.75 mm) as base flow (Figure 2b).

Flow (overland flow and base flow) was higher in CW. The mean daily flow rate for CW was 0.0113 m^3 s^{-1}, with a maximum of 0.0216 m^3 s^{-1} and a minimum of 0.0102 m^3 s^{-1}, while in SW, mean, maximum and minimum flow rates were 0.0061, 0.0168 and 0.0031 m^3 s^{-1}, respectively.

SW presented a greater amplitude of base flow (0.0031–0.0117 m^3 s^{-1}, which corresponds to 2.03–7.58 mm) (Figure 2a), while CW had a greater amplitude of overland flow (0.0000–0.0111 m^3 s^{-1}, which corresponds to 0.00–5.02 mm) (Figure 2b).

The mean daily value (period of 2 years) was 3.73 mm for base flow and 0.23 mm for overland flow in SW, and 5.03 mm for base flow and 0.09 mm for overland flow in CW. Of the total precipitation recorded during the 2 years of study (4,944 mm in SW and 4,691 mm in CW), 3.5% (174 mm) and 1.4% (67 mm) was overland flow, and 56% (2,769 mm) and 79.6% (3,732 mm) was base flow in SW and CW, respectively.

This generates an accumulated water yield (overland flow and base flow) of 29,428 m^3 ha^{-1} from SW and 37,993 m^3 ha^{-1} from CW

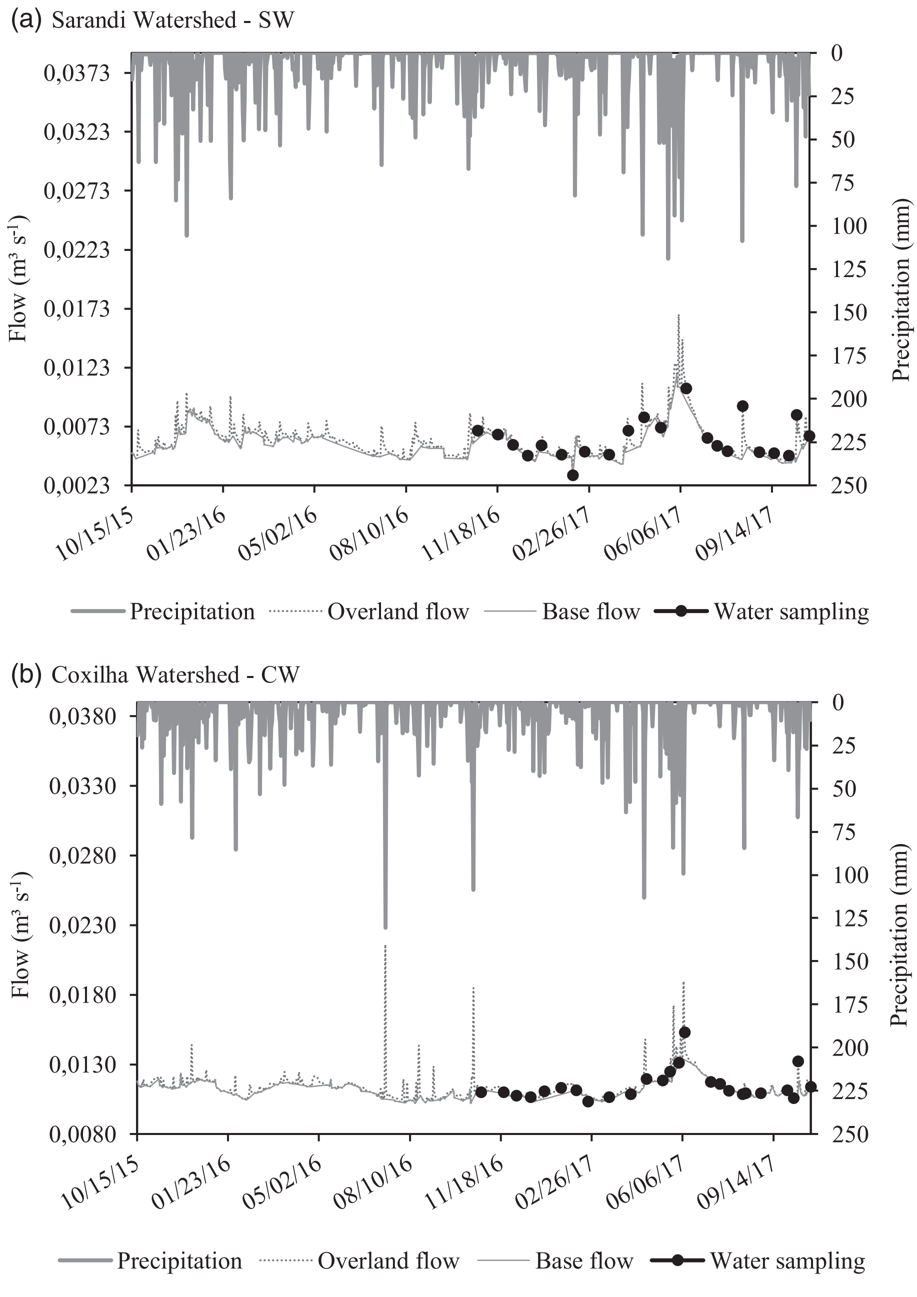

FIGURE 2 Precipitation, overland flow, base flow and water sampling during the study period in the Sarandi (a) and Coxilha (b) watersheds

(27,693 and 37,323 $m^3\ ha^{-1}$ as base flow and 1,735 and 667 $m^3\ ha^{-1}$ as overland flow, for SW and CW, respectively) during these 2 years.

3.2 | Water quality

Principal components analysis (Figure 3) of samples collected from downstream areas identified a clear separation between watersheds (SW and CW), collection dates (base flow and precipitation events) and agricultural crops (summer and winter). Overall, the concentration of all parameters was higher in downstream (Tables 5 and 6). Using the mean concentration considering the base flow and the precipitation events (Figure 3 left), component 1 (PC1), which explains approximately 69% of the data variation, is represented by TS, TN, NH_4-N, SP, PP, TP and NO_3-N and shows separation of the watersheds in such a way that SW has lower concentrations than CW. Component 2 (PC2), which explains approximately 23% of the data variation, is represented by BP, PN and TOC and shows separation of the collection dates such that BP has higher concentrations in precipitation events in SW, and TOC has higher concentrations in precipitation events in CW, while PN has higher concentrations at base flow in both watersheds. Using the mean concentration of the summer and of the winter crop (Figure 3 right), component 1 (PC1), which accounts for approximately 60% of the data variation, is represented by NH_4-N, TN, SP, PP, TP and TS and shows the watershed separation in such a way that SW watershed presents concentrations lower than those for CW. Component 2 (PC2), which accounts for approximately 27% of the data variation, is represented by BP, PN, TOC and NO_3-N and shows the separation of samples by agricultural crop, so BP and PN have higher concentrations in the summer in both watersheds, while TOC and NO_3-N have higher concentrations in the winter agricultural crop mainly in CW. In general, according to principal components analysis, the highest concentrations these variables were observed in CW (Figures 4–6).

Regarding the different fractions, the greatest contribution of TN came from NO_3-N and PN in both watersheds (Figure 7 left). However, in SW, the NO_3-N values were lower than those for CW (52% compared to 64%, respectively), while PN values were higher (44% compared to 33%, respectively). PP (BPP + NBPP) contributed more than 75% of TP (Figure 7 right) in both watersheds. Most of the PP was BPP (in SW, 44% of TP is BPP upstream and 55% downstream; in CW, 49 and 24% of TP is BPP upstream and downstream, respectively). The sum of SP and BPP corresponds to BP; approximately 70% of TP was bioavailable in SW, upstream and downstream, while in CW, approximately 68% was bioavailable in P1 and 35% in P2.

3.3 | Annual losses of sediment and nutrients

The sediment and nutrient losses estimated by LOADEST were similar the simplified methodology adapted from Yang et al. (2007) (Figure 8). Figure S1 shows the plots from flow and concentration and Tables S1

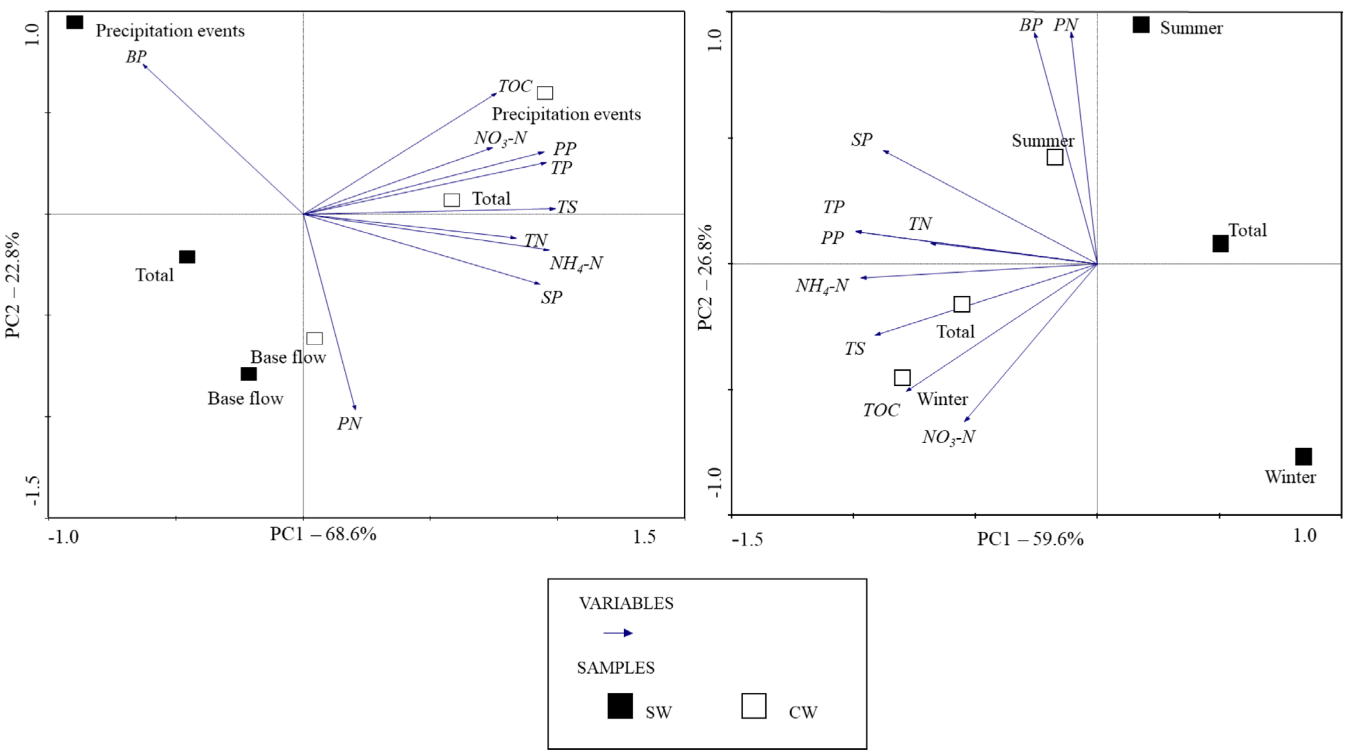

FIGURE 3 Analysis of principal components of the mean concentrations of total solids (TS), total organic carbon (TOC), nitrogen as nitrate (NO_3-N), ammonium (NH_4-N), particulate (PN), total nitrogen (TN), and phosphorus as soluble (SP), bioavailable (BP) particulate (PP) and total (TP) at downstream collections, in precipitation events and base flow (left) and in summer and winter crops (right) [Colour figure can be viewed at wileyonlinelibrary.com]

TABLE 5 Mean and standard deviation (±) of the concentrations of total solids (TS), nitrogen as ammonium (NH_4-N), nitrogen as nitrate (NO_3-N), particulate nitrogen (PN), total nitrogen (TN) and total organic carbon (TOC), turbidity, pH e electrical conductivity (EC) of samples from Sarandi (SW) and Coxilha (CW) watersheds

	TS	Turbidity		EC	NH_4-N	NO_3-N	PN	TN	TOC
	Mg L^{-1}	NTU	pH	µS cm^{-1}	————————————	——————mg L^{-1}	————————	————————	————————
SWP1-T	48.5 ± 41.7	6.2 ± 6.98	5.7 ± 0.40	23.6 ± 3.91	0.07 ± 0.12	1.14 ± 0.46	0.94 ± 0.60	2.15 ± 0.69	1.84 ± 1.95
SWP1-S	56.9 ± 33.6	8.7 ± 9.10	5.6 ± 0.34	24.4 ± 4.43	0.09 ± 0.16	0.93 ± 0.55	1.31 ± 0.58	2.33 ± 0.88	1.44 ± 2.51
SWP1-W	40.1 ± 48.6	3.8 ± 2.46	5.9 ± 0.42	22.7 ± 3.29	0.04 ± 0.04	1.36 ± 0.20	0.58 ± 0.38	1.98 ± 0.39	2.24 ± 1.14
SWP1-B	55.6 ± 36.9	7.7 ± 8.32	5.8 ± 0.47	24.0 ± 4.55	0.09 ± 0.14	1.05 ± 0.52	1.09 ± 0.63	2.24 ± 0.80	1.31 ± 2.21
SWP1-P	36.0 ± 49.0	3.6 ± 2.28	5.7 ± 0.25	22.9 ± 2.52	0.02 ± 0.04	1.30 ± 0.30	0.67 ± 0.48	2.00 ± 0.44	2.76 ± 0.87
SWP2-T	50.9 ± 35.8	5.6 ± 6.06	5.8 ± 0.49	23.9 ± 3.88	0.06 ± 0.06	1.07 ± 0.53	0.93 ± 0.66	2.06 ± 0.58	1.37 ± 1.48
SWP2-S	55.6 ± 34.2	7.1 ± 8.21	5.7 ± 0.60	24.1 ± 3.52	0.08 ± 0.07	0.66 ± 0.35	1.34 ± 0.64	2.08 ± 0.70	1.31 ± 1.94
SWP2-W	46.3 ± 38.5	4.2 ± 2.24	5.9 ± 0.33	23.7 ± 4.37	0.04 ± 0.05	1.47 ± 0.32	0.52 ± 0.35	2.04 ± 0.45	1.44 ± 0.91
SWP2-B	58.1 ± 33.6	6.4 ± 7.31	5.8 ± 0.57	24.2 ± 4.26	0.09 ± 0.07	0.94 ± 0.59	1.09 ± 0.69	2.12 ± 0.57	1.20 ± 1.71
SWP2-P	38.5 ± 38.5	4.4 ± 2.78	5.9 ± 0.35	23.4 ± 3.30	0.02 ± 0.01	1.29 ± 0.32	0.65 ± 0.52	1.96 ± 0.61	1.67 ± 1.00
Mean SW	49.7 ± 38.4	5.9 ± 6.46	5.8 ± 0.44	23.7 ± 3.85	0.06 ± 0.09	1.11 ± 0.49	0.94 ± 0.62	2.11 ± 0.63	1.61 ± 1.73
CWP1-T	61.1 ± 35.8	11.8 ± 32.94	5.4 ± 0.36	32.4 ± 7.45	0.07 ± 0.06	2.29 ± 0.61	1.18 ± 0.94	3.54 ± 1.20	3.68 ± 4.10
CWP1-S	61.3 ± 35.6	6.4 ± 5.25	5.5 ± 0.23	34.4 ± 2.94	0.07 ± 0.05	2.50 ± 0.25	1.84 ± 1.08	4.42 ± 1.09	2.00 ± 2.40
CWP1-W	60.9 ± 37.2	15.4 ± 42.52	5.2 ± 0.39	31.1 ± 9.21	0.07 ± 0.07	2.15 ± 0.74	0.74 ± 0.49	2.96 ± 0.88	4.80 ± 4.67
CWP1-B	58.6 ± 38.2	5.2 ± 4.82	5.4 ± 0.36	33.4 ± 4.15	0.07 ± 0.05	2.46 ± 0.30	1.45 ± 1.24	3.99 ± 1.23	2.02 ± 2.09
CWP1-P	63.0 ± 35.1	16.9 ± 43.83	5.3 ± 0.37	31.7 ± 9.37	0.07 ± 0.07	2.16 ± 0.75	0.97 ± 0.58	3.20 ± 1.08	4.98 ± 4.86
CWP2-T	85.9 ± 90.9	16.0 ± 42.26	5.7 ± 0.26	27.1 ± 4.61	0.11 ± 0.15	1.84 ± 0.39	0.95 ± 0.56	2.91 ± 0.71	3.26 ± 4.98
CWP2-S	53.9 ± 20.4	1.8 ± 1.44	5.7 ± 0.20	26.8 ± 4.57	0.08 ± 0.06	1.82 ± 0.41	1.48 ± 0.37	3.39 ± 0.69	1.17 ± 2.17
CWP2-W	107.2 ± 112.6	25.4 ± 53.11	5.6 ± 0.30	27.3 ± 4.78	0.14 ± 0.19	1.86 ± 0.39	0.60 ± 0.32	2.59 ± 0.54	4.64 ± 5.85
CWP2-B	58.2 ± 30.0	1.3 ± 0.75	5.6 ± 0.27	25.4 ± 5.61	0.08 ± 0.06	1.76 ± 0.27	1.14 ± 0.47	2.99 ± 0.54	0.94 ± 1.40
CWP2-P	107.7 ± 115.8	27.5 ± 54.51	5.7 ± 0.26	28.4 ± 3.28	0.14 ± 0.20	1.91 ± 0.46	0.80 ± 0.59	2.85 ± 0.84	5.07 ± 6.01
Mean CW	73.5 ± 69.5	13.9 ± 37.56	5.5 ± 0.35	29.8 ± 6.69	0.09 ± 0.12	2.07 ± 0.55	1.07 ± 0.77	3.23 ± 1.03	3.47 ± 4.52

Notes: All collections (T), collections in summer crop (S) and winter crop (W), collections in base flow (B), and precipitation events (P), collections at different points (upstream—P1 and downstream—P2).

and S2 show the equations e results, respectively from the LOADEST model. However, considering that LOADEST can produce biased load estimates when the model does not have a good adjustment (Table S1) due to the small amount of data evaluated, it was decided to present and discuss the results obtained by the simplified methodology, adapted from Yang et al. (2007).

The largest losses of sediments and nutrients were observed in CW (Figure 8). Sediment loss was 96% higher in CW (1,369 kg ha^{-1} yr^{-1}) compared to SW (698 kg ha^{-1} yr^{-1}). Phosphorus losses (Figure 8a) were also greater in CW (1.6 kg ha^{-1} yr^{-1} TP) compared to SW (0.8 kg ha^{-1} yr^{-1} TP), approximately 1% and 6% of the P applied through mineral fertilization in SW (76.2 kg ha^{-1}) and CW (35.2 kg ha^{-1}), respectively. For nitrogen, loss of NH_4-N + NO_3-N (Figure 8b) in SW was 17.6 kg ha^{-1} yr^{-1}, approximately 5% of the amount applied via mineral fertilizer in SW (342.8 kg ha^{-1}). In the CW, the nitrogen loss (35.2 kg ha^{-1} yr^{-1}) was much higher than that applied (6.6 kg ha^{-1}). Nitrogen inputs via animal waste and crop residues (straw and roots) were not accounted for. TOC also had highest losses in CW, when compared to SW (54.0 and 18.9 kg ha^{-1} yr^{-1}) (Figure 8b).

4 | DISCUSSION

4.1 | Flow and water yield

During events of high volume, most of the rainfall was converted to base flow in SW, while in CW, most of the rainfall was transformed into overland flow. Regarding the rainfall event that produced the highest peak discharge, the overland flow for CW was 51% of total discharge flow and for SW it was 23%. The watersheds have different agricultural systems under no-tillage but the differences in the flow data (overland flow and base flow) during events of precipitation can be explained by the presence and absence of terraces. In the SW with continuous crop production there are terraces (more specifically the level terraces), while in the CW with crop-livestock integration there are no terraces implemented. Deuschle et al. (2019), in a study on agricultural hillslopes in Southern Brazil concluded that even in no-tillage under crop rotation intensification with high soil cover, complementary practices such as terraces are necessary to control runoff. Terraces, independent of the type, decrease the length of the hillside, but the level terrace type is built to retain all surface runoff (Denardin,

TABLE 6 Mean and standard deviation (±) of the concentrations of soluble phosphorus (SP), bioavailable phosphorus (BP), particulate phosphorus (PP), bioavailable particulate phosphorus (BPP), non-bioavailable particulate phosphorus (NBPP) and total phosphorus (TP), of samples from Sarandi (SW) and Coxilha (CW) watersheds

	SP	BP	PP	BPP	NBPP	TP
	mg L^{-1}					
SWP1-T	0.015 ± 0.03	0.041 ± 0.03	0.044 ± 0.04	0.026 ± 0.02	0.019 ± 0.04	0.059 ± 0.06
SWP1-S	0.022 ± 0.04	0.052 ± 0.04	0.058 ± 0.05	0.029 ± 0.02	0.029 ± 0.05	0.081 ± 0.08
SWP1-W	0.008 ± 0.01	0.030 ± 0.01	0.030 ± 0.02	0.022 ± 0.01	0.008 ± 0.02	0.038 ± 0.02
SWP1-B	0.020 ± 0.03	0.043 ± 0.04	0.047 ± 0.05	0.022 ± 0.02	0.025 ± 0.04	0.068 ± 0.07
SWP1-P	0.006 ± 0.00	0.037 ± 0.02	0.039 ± 0.02	0.031 ± 0.01	0.008 ± 0.02	0.045 ± 0.02
SWP2-T	0.008 ± 0.01	0.040 ± 0.03	0.050 ± 0.05	0.032 ± 0.03	0.018 ± 0.05	0.058 ± 0.06
SWP2-S	0.012 ± 0.01	0.048 ± 0.02	0.069 ± 0.07	0.036 ± 0.03	0.033 ± 0.08	0.081 ± 0.08
SWP2-W	0.004 ± 0.01	0.033 ± 0.02	0.031 ± 0.03	0.029 ± 0.03	0.002 ± 0.00	0.035 ± 0.03
SWP2-B	0.011 ± 0.01	0.039 ± 0.02	0.055 ± 0.07	0.028 ± 0.02	0.027 ± 0.07	0.065 ± 0.07
SWP2-P	0.004 ± 0.00	0.044 ± 0.03	0.041 ± 0.03	0.040 ± 0.03	0.002 ± 0.01	0.045 ± 0.03
Mean SW	0.012 ± 0.02	0.041 ± 0.03	0.047 ± 0.05	0.029 ± 0.02	0.018 ± 0.05	0.059 ± 0.06
CWP1-T	0.016 ± 0.04	0.056 ± 0.05	0.066 ± 0.06	0.040 ± 0.04	0.026 ± 0.05	0.082 ± 0.09
CWP1-S	0.012 ± 0.01	0.056 ± 0.05	0.067 ± 0.06	0.044 ± 0.05	0.023 ± 0.03	0.079 ± 0.06
CWP1-W	0.019 ± 0.06	0.056 ± 0.05	0.065 ± 0.07	0.037 ± 0.03	0.028 ± 0.07	0.084 ± 0.11
CWP1-B	0.010 ± 0.01	0.040 ± 0.02	0.047 ± 0.02	0.030 ± 0.02	0.017 ± 0.03	0.057 ± 0.03
CWP1-P	0.021 ± 0.06	0.069 ± 0.06	0.080 ± 0.08	0.048 ± 0.05	0.033 ± 0.07	0.102 ± 0.12
CWP2-T	0.012 ± 0.02	0.040 ± 0.01	0.102 ± 0.18	0.027 ± 0.02	0.074 ± 0.19	0.114 ± 0.19
CWP2-S	0.011 ± 0.01	0.041 ± 0.01	0.094 ± 0.10	0.030 ± 0.02	0.064 ± 0.11	0.105 ± 0.11
CWP2-W	0.013 ± 0.02	0.039 ± 0.02	0.107 ± 0.22	0.026 ± 0.01	0.081 ± 0.23	0.120 ± 0.24
CWP2-B	0.011 ± 0.01	0.040 ± 0.01	0.056 ± 0.05	0.029 ± 0.02	0.027 ± 0.05	0.067 ± 0.05
CWP2-P	0.014 ± 0.02	0.040 ± 0.02	0.138 ± 0.23	0.026 ± 0.02	0.112 ± 0.24	0.151 ± 0.25
Mean CW	0.014 ± 0.03	0.048 ± 0.04	0.084 ± 0.13	0.034 ± 0.03	0.050 ± 0.14	0.098 ± 0.15

Notes: All collections (T), collections in summer crop (S) and winter crop (W), collections in base flow (B), and precipitation events (P), collections at different points (upstream—P1 and downstream—P2).

Kochhann, Faganello, Denardin, & Santi, 2012; Gassman et al., 2006; Shi et al., 2012). This soil conservation practice improves the quality and availability of water (Londero et al., 2018; Magalhães, 2013; Merten et al., 2015). Systems where most of the rainfall is converted to surface runoff indicate a decrease in water quality due to an increase in the transport of sediments and runoff associated pollutants (Bortolozo et al., 2015; Ding et al., 2016; Lourençato et al., 2015; Ramos et al., 2014; Ribeiro et al., 2014) as well as a decrease in water supply due to low recharge (Durães & De Mello, 2013; Magalhães, 2013).

Considering the percentage of rainfall transformed on groundwater recharge (base flow), both watersheds had a higher proportion (greater than 50% from the 2-year period), highlighting the lower atmospheric demand due to meteorological conditions of the Cfa climate. Higher proportion of base flow compared to overland flow observed in the entire period of study for both watersheds are also observed during specific events, however, in those events with high precipitation, most of the rainfall was converted into base flow in the SW, while in CW most of the rainfall was converted in overland flow (Figure 2). So, if in the entire period the proportion of base flow in SW is lower compared to CW (56 and 80%, respectively), in high discharge events it was higher (77 and 49%, respectively).

4.2 | Water quality

The downstream represents all drainage from the watershed, so higher values were expected compared to upstream, mainly during rainfall events (Table 5). In general, it was identified differences between watersheds (SW and CW), collection dates (base flow and precipitation events) and agricultural crops (summer and winter), highlighting better quality in the SW, in the base flow and in the winter crops (Figure 1), however, different from SW, the water quality in the CW was worst in the winter crops. During the winter, the CW was cultivated with oats under grazing of beef cattle, which could explain the higher concentration of water quality parameters (Lanzanova et al., 2007). In addition to the low soil cover due to the limited crop systems with soybean-oat and the possibility of compaction of the soil by grazing, the sediment and nutrients transport in this watershed is maximized by the absence of terraces (Gassman

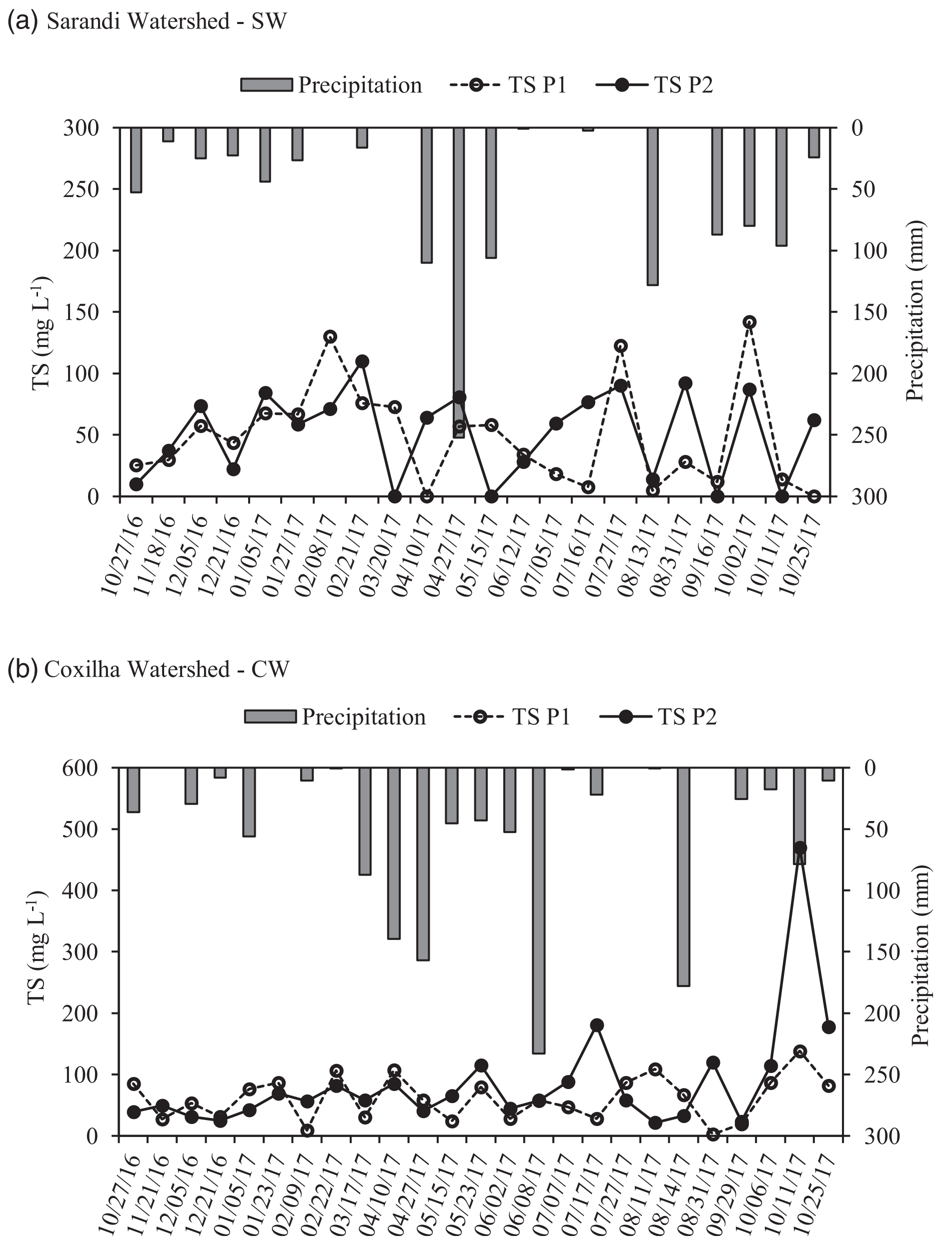

FIGURE 4 Precipitation (sampling day and 2 days before) and total solids concentration (TS) at upstream (P1) and downstream (P2) in the Sarandi (a) and Coxilha (b) watersheds

et al., 2006; Londero et al., 2018; Shi et al., 2012) and by insufficient riparian vegetation (Bortolozo et al., 2015). In the SW, the agricultural system is based on seed production, and the higher concentration of water quality parameters during the summer crop was possibly due to lower soil cover by maize; maize for seed production is cultivated with a larger spacing than the other crops (0.6 m maize; 0.45 m soybean; 0.17 m wheat and oats). Larger spacings leave the soil unprotected and susceptible to water erosion, especially in the initial phase of crop development. This effect is worst if there is low soil cover by straw.

Although the concentrations of water quality parameters in SW were better (Table 5), they could be even lower if the drainage channel had adequate riparian vegetation. In a study with native grass vegetation, Bortolozo et al. (2015) found 66, 84 and >80% water, sediment and nutrient retention, respectively, with a 30-m vegetation buffer.

Turbidity is usually highly related to sediment concentration (Merten, Minella, Horowitz, & Moro, 2014); however, in both watersheds, the correlation was very low, which was possibly due to the database containing mostly low values for TS (Minella, Merten, Rollof, & Abreu, 2009). TS reproduces the amount of sediment that is transported through surface runoff, and studies have shown that approximately 60% of suspended sediments in water bodies come from cultivated land (Tiecher, Caner, Minella, Bender, & dos Santos, 2016; Tiecher, Caner, Minella, & dos Santos, 2015). Bertol et al. (2007) comparing losses by water erosion in different management systems demonstrate that no-tillage systems are the most efficient, reducing sediment and water loss by 84 and 59%, respectively. Therefore, management practices to avoid the removal, transport and deposition of sediments, even in no-tillage, such as high soil cover by straw, terraces and riparian vegetation, are necessary to avoid water

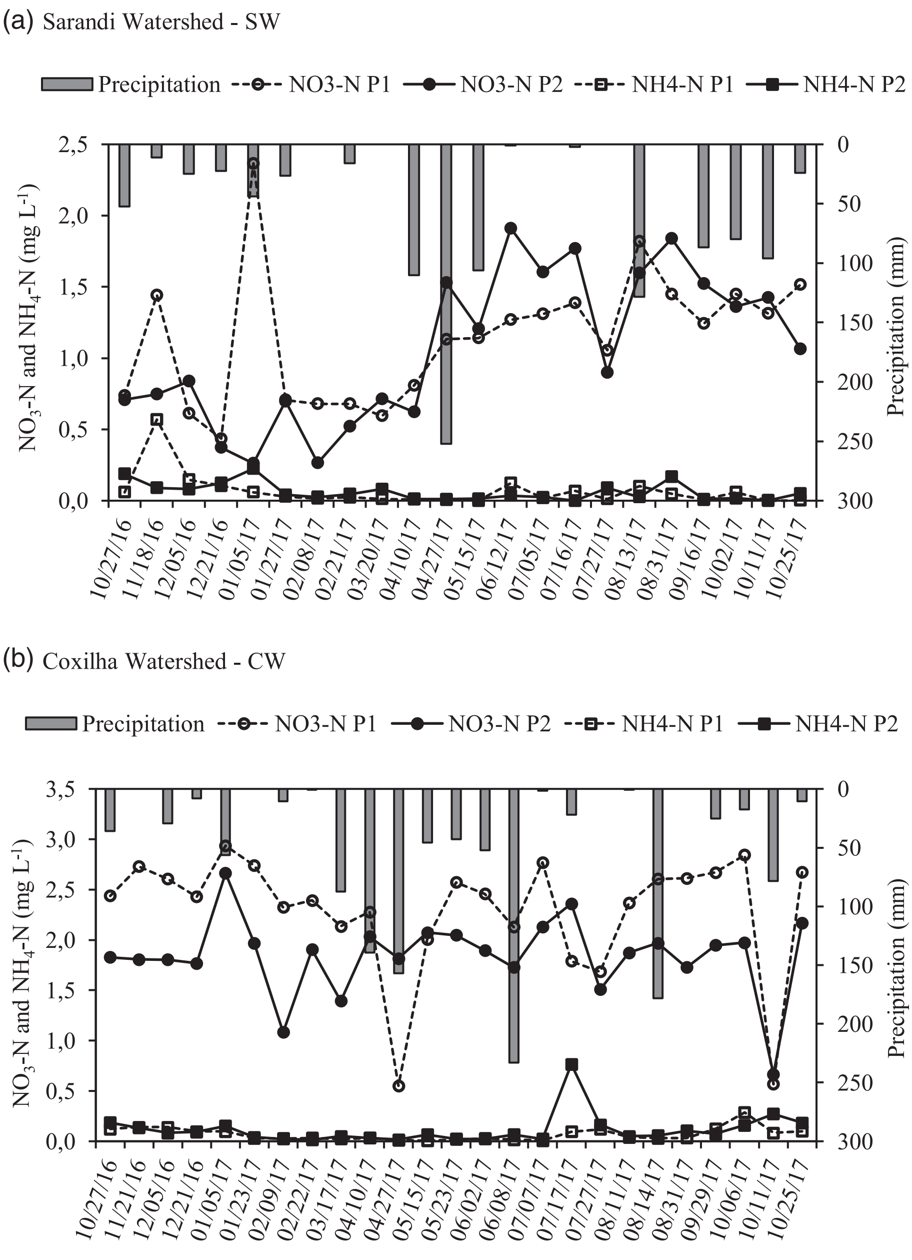

FIGURE 5 Precipitation (sampling day and 2 days before) and concentration of soluble nitrogen (nitrate [NO_3-N] and ammonium [NH_4-N]) at upstream (P1) and downstream (P2) in the Sarandi (a) and Coxilha (b) watersheds

degradation by agricultural activity. The values for electrical conductivity (Table 5) were low when compared to those considered as potential pollution problems, values higher than 100 μS cm^{-1} according to CETESB (2009). On-the-other-hand, they are high compared with those from other studies in agricultural watersheds (Ribeiro et al., 2014). High values of electrical conductivity were expected since these watersheds were cultivated under no-tillage systems with a high input of fertilizers.

Soil nitrogen can reach water bodies as soluble and particulate nitrogen and it can cause environmental and human health problems. TN is associated with eutrophication problems, NO_3-N with human health problems (methaemoglobinaemia and cancer), and NH_4-N (unionized NH_3) with aquatic life problems (Haygarth & Jarvis, 2002; Lal & Stewart, 1994). In soil conditions, most of the NH_4-N rapidly turns into NO_3-N due to nitrification (Silva & Vale, 2000), potentializing this loss. So, this explains the higher concentrations of NO_3-N when compared to NH_4-N in both watersheds (Figure 5, Table 5). NH_4-N, due to its positive electric charge binds to colloids in the soil. However, NO_3-N has a negative charge and, therefore, a greater potential for losses mainly via subsurface flow (Haygarth & Jarvis, 2002; Lal & Stewart, 1994). PN represents the organic fraction plus the mineral fraction adsorbed to the sediments being transported mainly via surface runoff.

NO_3-N concentrations were higher in CW (Figure 5, Table 5), and this can be a consequence of the crop–livestock system. The higher NO_3-N concentrations can be associated with manure addition with direct effect by the amount of N added and by increasing the microbiological activity. On the other hand, when no-tillage is well conducted, the tendency for water to be lost by subsurface flow carrying NO_3-N is much higher (Sangoi, Ernani, Lech, & Rampazzo, 2003). Even in the

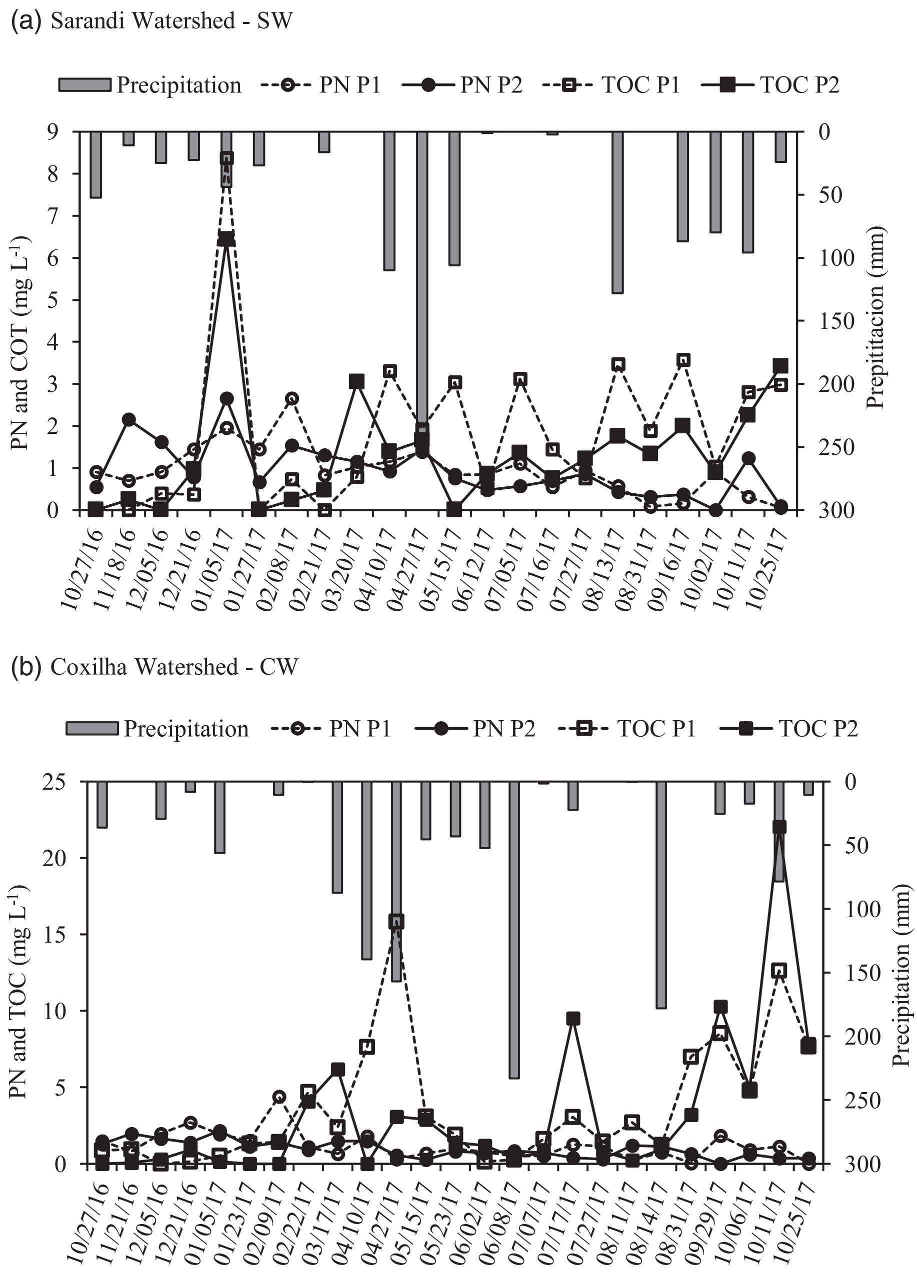

FIGURE 6 Precipitation (sampling day and 2 days before) and concentration of particulate nitrogen (PN), and total organic carbon (TOC) at upstream (P1) and downstream (P2) in the Sarandi (a) and Coxilha (b) watersheds

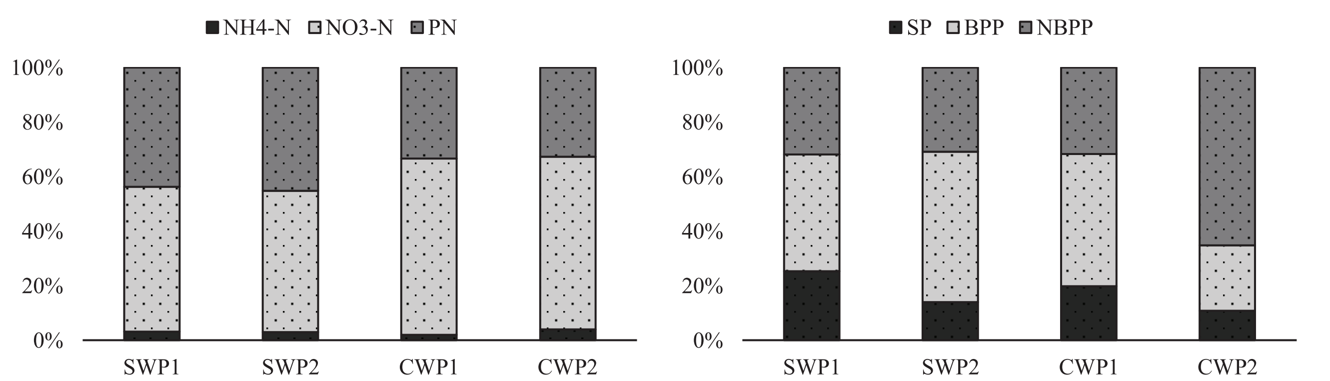

FIGURE 7 Percentage of mean concentration of total nitrogen (TN) as ammonium (NH_4-N), nitrate (NO_3-N) and particulate nitrogen (PN) (left) and of total phosphorus (TP) as soluble (SP), bioavailable particulate (BPP) and non-bioavailable particulate (NBPP) (right) in water of the Sarandi (SW) and Coxilha (CW) watersheds, at upstream (P1) and downstream (P2)

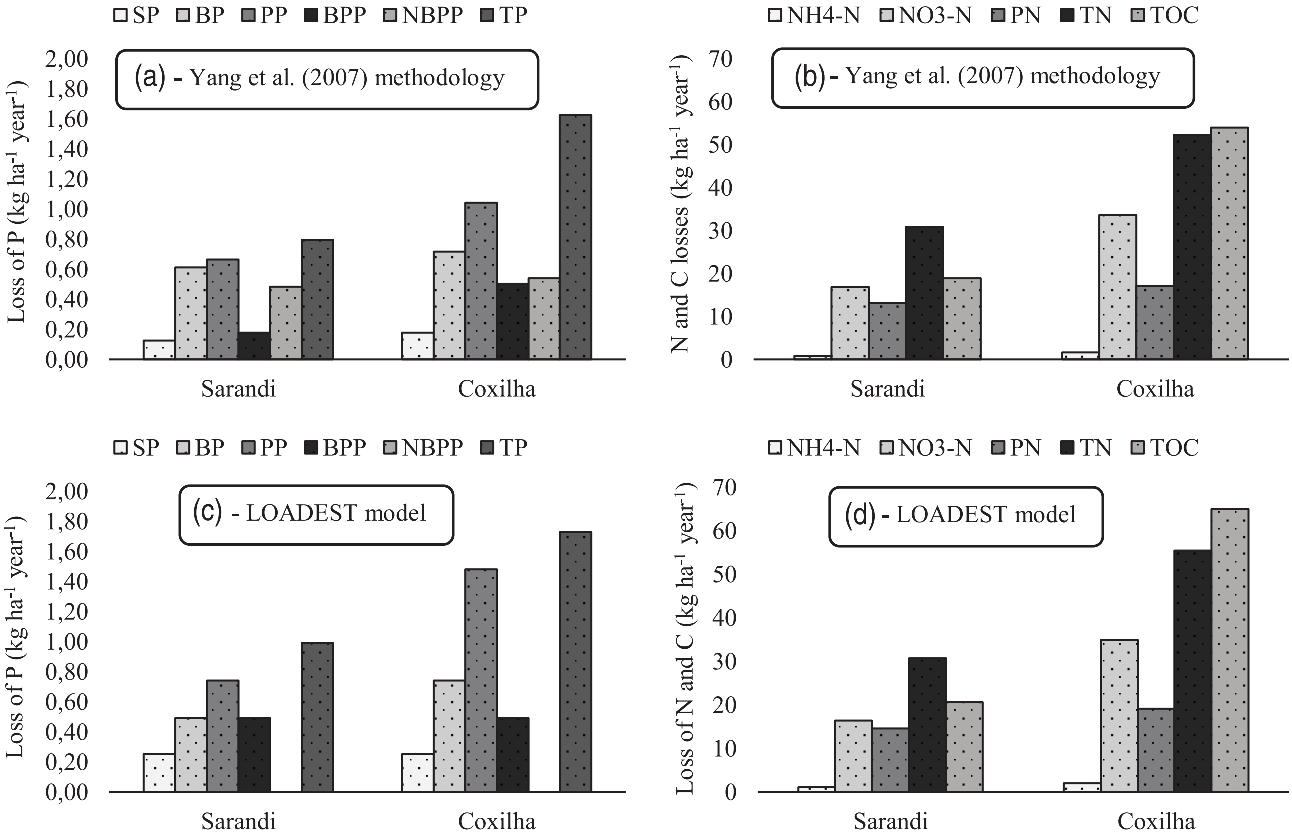

FIGURE 8 Annual loss of phosphorus as soluble (SP), bioavailable (BP), particulate (PP), bioavailable particulate (BPP), non-bioavailable particulate (NBPP), and total (TP) (a and c); nitrogen as ammonium (NH_4-N); nitrate (NO_3-N) particulate (PN) and total (TN) and total organic carbon (TOC) (b and d) in Sarandi and Coxilha watersheds, obtained by the adapted Yang et al.(2007) methodology (a and b) and by LOADEST model (c and d)

absence of terracing, which means no retention of surface runoff, the data show a greater contribution of subsurface flow on NO_3-N transport, since the highest concentrations were observed upstream in CW (Figure 5, Table 5). Moreover, studies show that differences in NO_3-N loss may occur due to crop type, being higher in soybean than in maize (Guadagnin et al., 2005), which also explains the difference between watersheds during the summer (Table 5) as maize was grown in SW and soybean in CW.

Phosphorus is the limiting element for eutrophication and because it is poorly mobile in soil, the main way to reach water bodies is by surface runoff, which demonstrates the importance of adopting soil management practices that mitigate runoff and, consequently, the loss of this nutrient (Haygarth & Jarvis, 2002). Phosphorus can be transported from soil to water as soluble and particulate. SP, BP and BPP are readily available to aquatic plants and organisms, and therefore their potential for contamination is short-term; since PP, NBPP and TP are not readily available, they represent a potential source of long-term contamination (Haygarth & Jarvis, 2002; Lal & Stewart, 1994; Sharpley, McDowell, & Kleinman, 2001).

During the summer crops, phosphate fertilizers were applied (198 kg ha^{-1} of P_2O_5 in SW and 59 kg ha^{-1} of P_2O_5 in CW). The soil in these areas already contains phosphorus at very high and extremely high levels (SBCS, 2016), respectively, therefore the soil acts as a source of phosphorus, since the adsorption sites may be saturated and then phosphorus is readily available to be transported as SP by surface and subsurface runoff (Guardini et al., 2012; Shore et al., 2017). The higher concentrations of bioavailable P in SW (Table 6) indicate a short-term pollution problem, while the higher concentration of NBPP downstream in CW show the potential for long-term pollution (Sharpley et al., 2001).

The data, when compared with CONAMA Resolution No. 357/2005 (Brasil, 2005), more specifically with freshwater class 2, show in general that the concentration of P in the stream (Table 6) is above the maximum limits allowed by legislation (0.030 mg L^{-1} of TP in a lentic and 0.050 mg L^{-1} of TP in no lentic water). Worldwide, these concentrations of TP are also associated with eutrophication (Correll, 1998; Haygarth & Jarvis, 2002). Therefore, farmers and professionals are required to be aware to correct not only soil use and management, but also fertilizer management. Worldwide, high rates of fertilizers are being unreasonably applied and represent a risk of water pollution.

Transport of nutrients from soil to water, especially in the particulate form, can be lower, even in terraced areas, if the presence of riparian vegetation is adequate. Bortolozo et al. (2015) obtained high retention of nutrients in runoff with 30 m of riparian vegetation. Ribeiro et al. (2014), studying the Campestre watershed, Colombo, PR, showed that riparian vegetation reduces the potential for water pollution, since lower concentrations of pollutants, mainly nutrients, are found in areas with adequate riparian vegetation. The relationship among agricultural systems and water quality is part of a complex web involving natural resources and adoption of best management practices by farmers. For Daloğlu, Nassauer, Riolo, and Scavia (2014) the decision to adopt conservation practices by farmers is a slow process that requires trial and evaluation, so studies exploring whether or not substantial changes in water quality can be expected as a result of specific interventions can incentive farmers on adopting sustainable food production with environmental protection.

4.3 | Annual losses of sediment and nutrients

The values of sediment losses (rough estimate) in both watersheds (698 kg ha^{-1} yr^{-1} in SW and 1,369 kg ha^{-1} yr^{-1} in CW) are lower than those obtained by other researchers. Dechen, Telles, Guimarães, and De Maria (2015) (study with soil and waters loss in a no-tillage system with different soil cover rates) obtained a loss of 12,570 kg ha^{-1} yr^{-1} with 90% soil cover. Raclot et al. (2009) (study with soil and water loss in different tillage systems and scale effect) obtained a loss of 2,500 kg ha^{-1} yr^{-1} in a field with a no-tillage system. On the other hand, the values are higher than those from the study of Merten et al. (2015) with a no-tillage system in Paraná (14 years of data collection); they found soil loss of 400 kg ha^{-1} yr^{-1} in small plots (up to 77 m^2) and 50 kg ha^{-1} yr^{-1} in large plots (up to 10,000 m^2). It is known that, in general, soil losses at large plots are lower than in small plots, so soil loss in a watershed should not be calculated considering the sum of individual fields (Raclot et al., 2009).

Agronomically, the phosphorus losses (maximum loss of TP was 1.6 kg ha^{-1} yr^{-1}, and 6% of applied P) (Figure 8) would not be a concern, but environmentally they indicate a problem, considering that the TP concentrations in these watersheds are above the critical limit to cause eutrophication (Correll, 1998; Haygarth & Jarvis, 2002). Regarding nitrogen and carbon losses, the values were higher compared with phosphorus losses (maximum loss of NH_4-N + NO_3-N, 35 kg ha^{-1} yr^{-1} and TOC, 54 kg ha^{-1} yr^{-1}). The presence of cattle and their manure, in CW, in the winter crop can explain the greater losses in CW. Manure on the soil surface is extremely vulnerable to losses by surface runoff (Cherobim, Huang, & Favaretto, 2017).

4.4 | Final considerations

Overall, the water quality was worst in the watershed characterized by production of soybean in the summer and oat with grazing in the winter, under no-tillage, without crop rotation and no terracing. Unfortunately, in most of the no-tillage systems in the southern region of Brazil, terraces have been removed from agricultural fields, and crop succession or even monoculture has been used which causes soil and water conservation problem. However, even with crop rotation and terraces in the watershed characterized by production of annual crop seeds under no-tillage factors such as soil compaction, low soil cover residue, saturated soil and insufficient riparian vegetation affect water, sediment and nutrients losses.

To reduce the potential risks of water pollution in agricultural areas, even in no-tillage, it is important to highlight the implementation of terraces and riparian vegetation as well as the maintenance of crop systems with high carbon production and soil cover throughout the entire year with appropriate fertilization management. These best management practices benefit the environmental quality and the economically rentability of the farmers once water is stored in the soil, minimizing problems of scarcity, improving the productive capacity of the soil and consequently increasing profitability.

The study with water quality was conducted for only 1 year, and the samples were manually grabbed in precipitation events and flow base, however, during the precipitation, only one sample was collected. We understand that a better result could be found if water samples were taken during the rising and falling of the hydrograph and for a longer period in several significant events, but unfortunately this was no possible in our monitoring, and can be a suggestion for future studies. In spite of the limited dataset collected during 1 year, monitoring of water quality under intensively cultivated subtropical agricultural watersheds are pioneering researches, and in our case revealed important results related to soil management practices and water fluxes and quality. Besides the changes in the sampling procedure and the long term monitoring, we also suggest for future studies paired small watersheds or paired large plots with specific contrasting conditions of land use and management to better understand the effect of the treatments.

ACKNOWLEDGMENTS

The authors are grateful to the National Council for Scientific and Technological Development (CNPq) for financial support (grants and scholarships) and to the Brazilian Agricultural Research Corporation (EMBRAPA) and Itaipu Binacional for field and financial contributions to the SoloVivo Project.

CONFLICT OF INTEREST

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of this article.

How to cite this article: Martíni AF, Favaretto N, De Bona FD, Durães MF, de Paula Souza LC, Goularte GD. Impacts of soil use and management on water quality in agricultural watersheds in Southern Brazil. *Land Degrad Dev*. 2020;1–18. https://doi.org/10.1002/ldr.3777