



Water, Sediment and Nutrient Retention in Native Vegetative Filter Strips of Southern Brazil

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Authors' contributions

This work was carried out in collaboration of all authors. Author FRB designed the study, managed the field work, performed the laboratory analyses, interpreted the data and wrote the first draft of the manuscript as part of the master dissertation at Soil Science Graduate Program of Federal University of Paraná State, Brazil. Author NF, advisor professor, helped on the study design, field work, laboratory analyses, interpretation of data, and final manuscript. Authors JD, AM and FMV, co-advisor professor, helped on the study design, field work, laboratory analyses, and interpretation of data. Author EDBS managed the statistical analyses. All authors read and approved the final manuscript.

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ABSTRACT

Vegetative filter strips (VFS) are areas adjacent to watercourses with the purpose of reducing sediment and nutrients contained within runoff water from cropland. The aim of this study was to evaluate the retention of water, sediment and nutrients in VFSs with 5, 10, 20 and 30 m widths exposed to simulated runoff water. The VFS chosen for this study were populated by native herbaceous vegetation with a predominance of grasses from South of Brazil. To simulate runoff water, a flow of 30 L min⁻¹ was applied to all plots. Simulated runoff water contained 3.22 g L⁻¹ of sediment and the nutrients concentration was 62.2; 40.9 and 170.3 mg L⁻¹ de P, NH₄-N and NO₃-N,

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respectively. As expected, we found the VFS (30 m) could retain a greater quantity of nutrients (>80%), water (66%) and sediment (84%). However, we found the VFS (of width 10 m) was the most efficient when considering area against nutrient (>70%), water (42%) and sediment (73%) retention. With a ever expanding human population and intensive land use in Brazil, efficient use of VFSs could reduce water pollution from agriculture field.

Keywords: Native grass; runoff; water quality; nitrogen; phosphorus.

1. INTRODUCTION

Despite major advances in agricultural production systems, soil and nutrient loss from runoff water is a major problem when considering water quality [1]. One way to minimize this problem is the use of vegetative filter strips (VFSs). A VFS consists of different types of vegetation (grasses, shrubs and trees) located between an agricultural field and a water source [2]. VFSs can also be inserted around the perimeter of an agricultural field, following the contour of the crop rows. The primary objective of the VFS is to retain sediment and chemicals contained within runoff water, thus acting as a filter between the field and the water source [3].

The retention mechanism of VFSs consists of reducing runoff water by creating a physical barrier. Its also acts as a filter with the deposition of pollutants associated with the sediment [2]. Soluble nutrients can also be retained by adsorption (sorption) to soil particles [4] or by infiltration (leaching). The nutrients captured in the system can later be absorbed by plants and

immobilized or transformed by microorganisms [5].

The efficiency of retention by a filter strip depends on several factors, including soil, slope, rainfall and type and width of vegetation. Among these factors, the width of the VFS receives special attention in agricultural systems, because it interferes on the amount of arable land wasted to preserve water [2,3,5]. The experimental conditions and the results obtained in different studies with filter strips are presented in Table 1.

For example, in a study with simulated runoff (sediment concentration of 4.43 g L⁻¹), [11] considered VFSs of width 8.3 to 16.1m, consisting of grass and shrub species on a silt loam soil. The VFSs could reduce sediment ~ 99.7% when compared to an area with no VFS. The losses of phosphorus and nitrogen were also considerably reduced (91.8% and 92.1%, respectively). Based on that results, the authors recommend the use of filter strips (of width 8 m) consisting of grasses and shrubs in environments of unknown non-point pollution sources.

Table 1. Retention of sediment, phosphorus and nitrogen by filter strips in agricultural areas under different conditions

Soil type	Flow type	Slope (%)	Vegetation	Width (m)	Retention (%)			Authors
					Sediment	Total-N	Total-P	
Loam	Simulated rainfall	5-16	Grass	4-9	53-98	47-93	49-93	[6]
Clay-loam	Simulated rainfall	6-7	Grass and shrubs	5-7	63-93	-	48-79	[7]
Fine-loamy	Simulated rainfall	3	Grass	3-6	65-76	28-46	37-52	[8]
Loam	Natural rainfall	3	Grass, shrubs and tree	6	93	80	72	[9]
Sandy-loam	Natural rainfall	2.5	Grass and tree	8-60	-	37-67	56-67	[10]
Silt-loam	Simulated runoff	4	Grass and shrubs	8-16	99	92	92	[11]

The width of the riparian VFS depends on the specific technical recommendations or laws of each country, region or state. The grass and forest that form the riparian vegetation may or may not be native [5]. The Department of Agriculture (USA) for example, suggests the use of three zones with different types of vegetation in the composition of a riparian strip to control diffuse pollution: 6 m of primary forest extending from the river banks, followed by 3 m of shrub vegetation, then 6 m of grass and bushes [12]. In Brazil, the New Forest Code [13] takes into account the width of the river to determine the corresponding width of riparian vegetation. Waterways narrower than 10 meters require a minimum width of riparian vegetation of 30 m, which should consist of native vegetation. In most of Brazil native vegetation is forest, but in the region of Campos Gerais (PR), the native vegetation is characterized by herbaceous vegetation with a predominance of grasses [14,15] while riverbanks normally comprise a narrow strip of wooded vegetation. This arrangement of riparian vegetation (in the presence of grass and forest) favors the retention of pollutants, thus protecting surface waters. In this region, the dominant farming system is no-tillage, which has proven effective in controlling soil loss [16] and sediment associated pollutants. However, the high concentration of soluble nutrients has been a concern for conservation systems [17]. Therefore, besides sediment retention, it is important to understand the retention capacity of soluble pollutants.

The aim of this study was to evaluate the retention of sediments and nutrients (soluble and particulate) in four widths of native vegetated strips (predominance of grasses) in the region of Campos Gerais, (PR, Brazil) and contribute to a better management in no-tillage agricultural areas to mitigate water pollution.

2. MATERIALS AND METHODS

2.1 Description of the Experimental Area

The study was conducted in the Porto Amazonas region of Campos Gerais (PR, Brazil; altitude 865 m, latitude 25°25'46"S and longitude 50°00'23"W). The climate is humid subtropical Cfb type, according to the Köppen classification, with mild summers and an annual average temperature ranging from 17 to 18°C. The average annual rainfall varies from 1400 to 1600 mm [18]. The soil is Inceptisol with a sandy clay

loam texture at 0-20 cm (Table 2) and a 10% slope.

The native vegetation of Campos Gerais (PR) is characterized by herbaceous vegetation with a predominance of grasses [14,15] with height around 60 cm. The most abundant is *Aristida jubata* (Arechav) Herter, a perennial specie (50 cm tall) forming compact clumps. Another common specie is *Andropogon bicornis* Lan, an erect plant that can reach 1 m in height with numerous stems forming a very dense cluster [19]. The experimental area was fully covered by this native vegetation.

We chose four widths of VFS (5, 10, 20 and 30 m) that were occupied predominantly with grasses (native). The widths were chosen based on literature review and on the Brazilian legislation. As described earlier, the Brazilian Forest Code [13] determines a minimum width of riparian vegetation of 30 m, which should consist of native vegetation. These VFSs, with 3 replicates (n=3 per VFS), were treated with simulated runoff water. The plots had areas of 5, 10, 20 and 30 m² (simple large rectangles - 5 x 1 m; 10 x 1 m; 20 x 1 m and 30 x 1 m). Plots were placed on a 10% slope (representative slope of the region) and bounded by metal plates (10 cm high) embedded 5 cm into the ground. At the bottom of the slope, the flow was channeled into a 75 mm diameter PVC tube connected to 12 L buckets.

The simulated runoff consisted of a mixture of top soil (10 cm) from the row crop field, nutrients (soluble fertilizers) and water from the river near the experimental area. Sediment and nutrients concentration added in the simulated runoff tanks (water from the river with soil and fertilizer) was based on concentrations obtained in studies where there was natural rainfall with no-tillage in the region of Campos Gerais (PR, Brazil) [20,21]. Sediment concentration added was 2.24 g L⁻¹ however, the retention was calculated from the total concentration of solids (3.22 g L⁻¹) contained in the simulated runoff tanks. Nutrient concentrations added to the simulated runoff tanks were 50 mg L⁻¹ P (186 g of monoammonium phosphate), 60 mg L⁻¹ NH₄-N (543 g of ammonium sulfate) and 200 mg L⁻¹ NO₃-N (828 g of calcium nitrate). However, retention was calculated by taking the average concentration from the samples collected in the tanks after the addition of soil and fertilizer.

The results obtained in the analysis of simulated runoff water were 62.2 mg L⁻¹ P, 40.9 mg L⁻¹ NH₄-N and 170.3 mg L⁻¹ NO₃-N. The mixture of soil and nutrients were manually homogenized (constantly) in a 1000 L tank. This tank was connected to a 310 L reservoir, which maintained a constant column of water. With the aid of a one inch hose connected to a specially manufactured distributor, the simulated runoff was distributed to the upper position of the plots. A flow rate of 30 L min⁻¹ was used in all plots to simulate a water depth of 60 mm h⁻¹ in an area of 30 m². Runoff was sampled every 10 minutes during two hours.

2.2 Calculation of Water, Sediment, Nitrogen and Phosphorus Retention

Simulated runoff was collected and agitated before a 0.5 L sample was retained for testing in plastic bottle. Samples were frozen until the chemical analysis. The water retention was calculated by subtracting the volume collected in the output from the volume applied and the values were expressed in percentage relative to starting quantities.

The sediment was obtained by drying an aliquot of 50 mL at 105°C. The sediment retention was calculated by subtracting the amount of sediment lost in the output from the amount applied and the values expressed in percentage relative to starting quantities.

Nitrogen as nitrate (NO₃-N) was determined by ultraviolet spectrometry (220 nm) with 10% sulfuric acid and metallic zinc to determine the interferences [22]. The nitrogen as ammonium (NH₄-N) was colorimetrically determined by phenate method [23] using spectrophotometer at 640 nm. The principle of the phenate method is the formation of an intensely blue compound, indophenol, by the reaction of ammonia with phenol and hypochlorite. The blue color is intensified with sodium nitroprusside. Total nitrogen was extracted by Kjeldahl digestion and

determined by the phenate method [23]. Since Kjeldahl digestion does not recover nitrogen as nitrate, total nitrogen (TN) was obtained by adding Kjeldahl nitrogen and nitrate [24]. Particulate nitrogen (PN) was obtained by taking the difference between the concentration of the total Kjeldahl nitrogen and NH₄-N.

The soluble reactive phosphorus (SP) was determined colorimetrically by spectrometry at 880 nm using ascorbic acid methodology [23]. The principle of the ascorbic method is the formation of antimony-phosphomolybdate, which is reduced by ascorbic acid producing an intense blue color. For analysis of the total phosphorus (TP), Kjeldahl digestion was applied [25] based on the methodology described in [23]. The phosphorus in the particle fraction (PP) was obtained by taking the difference between the levels of total phosphorus and soluble reactive phosphorus. The bioavailable phosphorus (BP) was extracted with a filter membrane impregnated with iron oxide according to [26,27]. The determination of total and bioavailable phosphorus after the extraction was by the ascorbic acid method [23].

The nitrogen and phosphorus retentions were calculated by subtracting the amount of nutrient lost in the output from the amount applied and the values expressed in percentage relative to starting quantities.

2.3 Statistical Analysis

The data were interrogated using a one-way analysis of variance (ANOVA) and multiple non-linear regression (P<0.01), allowing for an interaction between bandwidth and simulation time. For the regression, the model was $y(t, w) = a.tb.(t.w)c$, where t = time; w = width of filter strips; and a , b , and c are unknown constants to be estimated. All analyses were carried out using R version 2.11.0 [28].

Table 2. Soil physical attributes of the experimental area

Depth (cm)	Particle size (g kg ⁻¹)			ASI	Ds (g cm ⁻³)	Porosity (%)			MWDw (mm)	MWDd
	Clay	Silt	Sand			Micro	Macro	Total		
0-5	350	158	491	0.92	1.06	36.7	23.2	59.9	3.14	3.40
5-10	347	186	466	0.80	1.15	37.4	19.3	56.7	2.84	3.57
10-20	359	179	460	0.70	1.20	34.6	20.2	54.8	2.57	3.69

ASI, aggregate stability index (MWDw/MWDd); Ds, soil density; MWDw, mean weight diameter – wet; MWDd, mean weight diameter - dry

3. RESULTS AND DISCUSSION

3.1 Water and Sediment Retention

Retention of water and sediment demonstrated that native grass filter strips of all widths were more efficient at the beginning of the simulation (Fig. 1). In practical terms this indicates that rainfall with long duration, even with the presence of filter strips, could cause problems with runoff associated pollutants coming from agricultural areas. Taking the 30 m width as a baseline (66% water retention), the reductions in water retention for 5 m, 10 m and 20 m widths were 30%, 16% and 5%, respectively (Fig. 2). The increase in water retention (36-66%) as the strip widens is expected due to the increase of the area that provides infiltration. The soil physical attributes (500 g kg⁻¹ of sand and 20% of macroporosity) (Table 2) provide excellent

conditions for water infiltration. It is well known that water infiltration rate in sandy soils is higher than in silt and clay soils (2, 5, 7, 16). The maximum retention of accumulated runoff (66%) (Fig. 2) (sandy clay loam soil) was lower than that obtained by [11] (77 to 91%) (silt soil) and [7] (36 to 82%) (clay loam soil). However, the slope used in those studies varied from 4 to 7%, whereas in the present study was 10%.

Sediment retention by time (Fig. 1) indicates that even a 5 m strip was efficient at retaining sediment from simulated runoff water over time. The physical barrier of vegetation, independent of its width, had a considerable influence on the sediments retention [5]. This could be confirmed by the higher ratio of retention/area (%/m²) in the 5 m strip (Table 3) (the greater the difference between ratios (retention/area), the smaller the difference between widths).

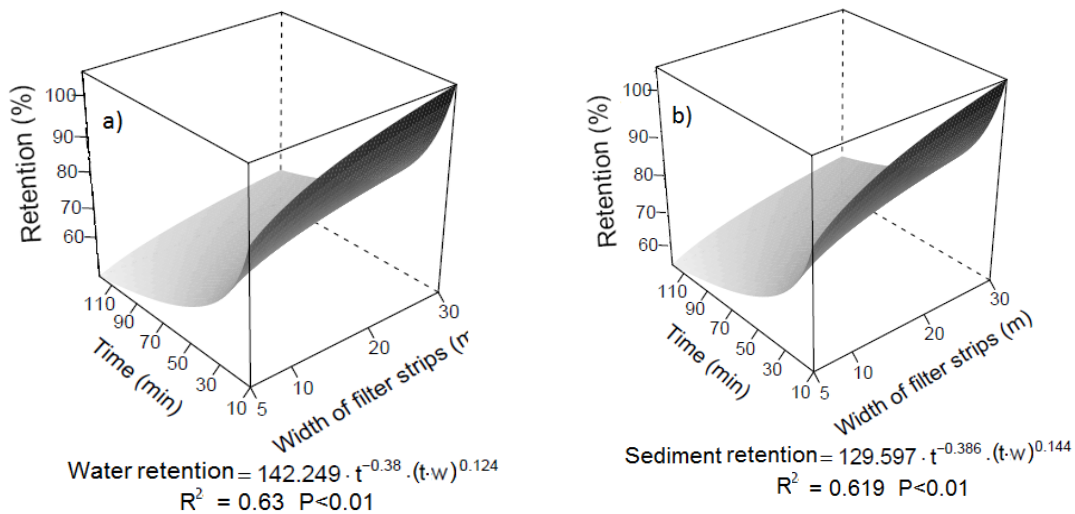


Fig. 1. Water (a) and sediment (b) retention in each sampling time at different widths of vegetative filter strips (VFS), where w= width of VFS and t= time

Table 3. Relationship between retention (%) and plot area (m²) at different widths of vegetative filter strips

VFS	R	TS	TN	NH ₄ -N	NO ₃ -N	PN	TP	SP	PP	BP
m(%/m ²).....									
5	7.26	13.25	12.55	12.46	12.46	13.94	12.01	9.81	15.32	12.19
10	5.00	7.48	7.24	7.43	7.12	8.18	7.18	6.59	8.18	7.23
20	3.03	4.06	3.98	4.12	3.90	4.45	4.00	3.86	4.29	4.02
30	2.20	2.81	2.76	2.87	2.71	3.06	2.79	2.73	2.92	2.80

VFS, widths of vegetative filter strip; R, runoff; TS, total solids; TN, total nitrogen; NH₄-N, ammonium-nitrogen; NO₃-N, nitrate-nitrogen; PN, particulate nitrogen; TP, total phosphorus; SP, soluble phosphorus; PP, particulate phosphorus; BP, bioavailable phosphorus

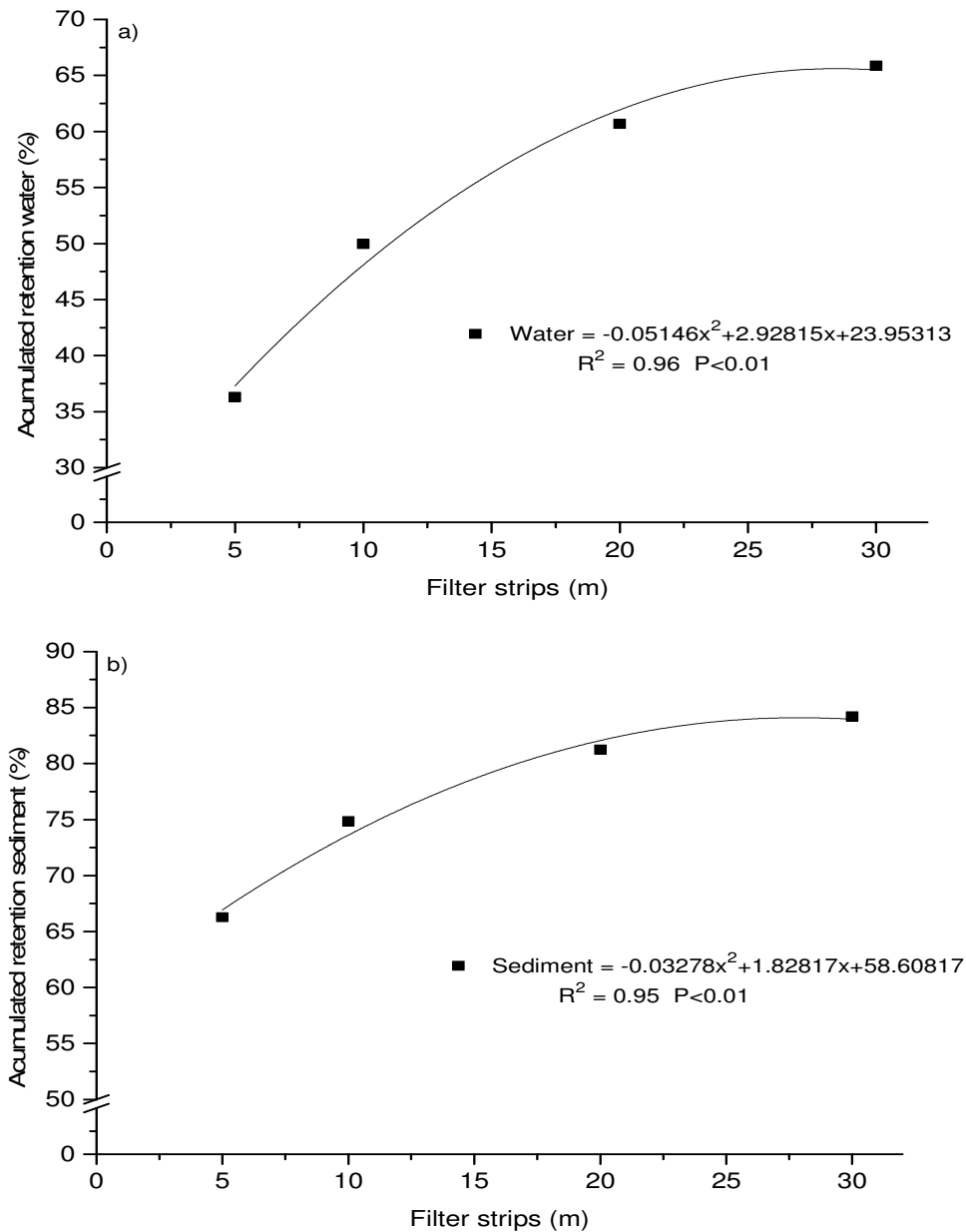


Fig. 2. Retention of accumulated water (a) and sediment (b) at different widths of vegetative filter strips within two hours of simulation

The maximum accumulated sediment retention (84%) was obtained by the 30 m filter strips (Fig. 2). The 5, 10 and 20 m strips had retentions reduced by 18%, 9% and 3% respectively, compared to the 30 m strip. Despite the fact that a 10 m VFS does not provide maximum retention, we can consider it as one of the best management practices with regard to sediment retention (>70%). It provides a good trade off

because its retention is not much less than 30 m strips (9% less) but uses considerably less area.

Simulated runoff generates a higher proportion of finer sediments compared to natural runoff, and it is well known that larger particles retained more easily than smaller. Therefore, the sediment retentions (66 to 84%, Fig. 2) could be greater under natural runoff conditions. Besides the size of the sediment particles, height and density of

the plants will also affect the retention of the sediment [3]. Despite the fact that it is a native field (predominance of grasses) the non-uniform distribution of plants could also have reduced the efficiency of sediment retention. The low density of plants can allow the formation of alternative surface drainage routes, reducing the holding capacity of the sediments by filter strips [2]. Furthermore, greater slope reduce retention due to the increased runoff [29]. In a study of simulated runoff (4.43 g L^{-1} sediment) in a silt loam soil, [11] observed sediment retention ranging from 78% to 94% in 8.3 to 16.1 m vegetation strips (4% slope) with native grasses with or without shrubs. Another study [30] of native grass and legume strips (15 m) in clay soil on a 2 to 5% slope showed 84% sediment retention. Comparing different types of vegetation and width on a 7% slope in a clay loam soil, [7] found that 7 and 15 m VFSs with grass provided sediment retention of 76% and 93%, respectively. Many other studies have shown that vegetated filter strips have been effective on removing sediment and nutrients transported by runoff; however, the efficiency varies depending on the experimental condition (Table 1).

3.2 Nitrogen Retention

The weighted average concentrations for all forms of nitrogen were reduced by filter strips (Table 4). However, the efficiency of filter strips was greater for particulate-N (76%) followed by $\text{NH}_4\text{-N}$ (60%) in a 30 m VFS. Particulate-N corresponds to the N associated to the sediment (mostly organic N) [24], so it is expected to have a good correlation with sediment retention. $\text{NH}_4\text{-N}$ and $\text{NO}_3\text{-N}$ are soluble, but $\text{NH}_4\text{-N}$, being a cation, is easily adsorbed by the surface negative charges of sediment particles [4], thereby increasing the $\text{NH}_4\text{-N}$ retention by trapped sediment. Being an anion, the $\text{NO}_3\text{-N}$ is not adsorbed by the negatively charged surface of sediment particles [4]. Therefore infiltration (leaching) had an especially important role for retention of $\text{NO}_3\text{-N}$. Absorption by foliage as well as microbiological changes may not be significant because of the short time of the experiment (two hours simulation). Long term experiments demonstrated a high efficiency on $\text{NO}_3\text{-N}$ removal by biological assimilation and denitrification on both natural and constructed riparian forests and wetlands [31]. Total-N consisted largely of $\text{NO}_3\text{-N}$, a fact that may have contributed to the lower efficiency of the

filter strips to reduce the total-N concentration (Table 4).

Particulate-N and $\text{NH}_4\text{-N}$ had the greatest accumulated retention compared to $\text{NO}_3\text{-N}$ and total-N, but all nitrogen forms had the greatest retention in the 30 m strip (Fig. 3). However, observing the variation of the nitrogen retentions obtained among filter strips (Fig. 3), we can recommend the 10 m strip (average of 75%) as one of the best management practices with regard to nitrogen retention (>75%). [32] reported that most of the particles and pollutants attached to the sediment were retained in the first 10 m of a VFS. In our study, on overall, the accumulated retention of nitrogen was greater than other studies [8,33,34,35].

On average, 92% total-N was retained in soluble form (18% as $\text{NH}_4\text{-N}$ and 74% as $\text{NO}_3\text{-N}$) while particulate-N contributed to only 8% in the total composition. The high concentration of soluble nitrogen in the total-N fraction occurred due to the high concentration of $\text{NO}_3\text{-N}$ (170.3 mg L^{-1}) added to the simulated runoff.

3.3 Phosphorous Retention

Reductions in the weighted average concentrations of PP (particulate phosphorus) were larger than TP (total phosphorus), SP (soluble phosphorus) and BP (bioavailable phosphorus) (Table 4) in all filter strips. The PP represents the P associated to sediment particles [1], so it is expected to have a better efficiency than soluble-P as the sediment is retained by the VFS. However, the concentration of soluble-P was also reduced after passing through the VFS, especially in the 30 m strip (Table 4). It is well known that P has preponderance to specific adsorption with soil particles [4], so the physical barrier by filter strip, not only the leaching mechanism, worked to reduce soluble-P concentrations.

The bioavailable P represents the soluble-P plus the particulate bioavailable P [26,36], which is readily available to growing aquatic plants. Larger filter strips had a better efficiency decreasing BP concentration (Table 4).

There was not a significant variation in accumulated retention of all forms of phosphorous; 88% being the maximum accumulated retention obtained for the PP, followed by TP (84%) and BP (84%) and finally SP (82%) in a 30 m VFS (Fig. 4). These

retentions, on overall, were higher than in other studies with filter strips consisting of grasses [6,9,11,30].

The results obtained demonstrate that the 30 m strip has the most potential for retention of all

forms of phosphorus; however, lower widths can also be effective; for example, 10 m filter strips present accumulated retentions of 72, 66, 82 and 72% for TP, SP, PP and BP, respectively. So, again, the 10 m filter strip could be recommended to maximize land usage.

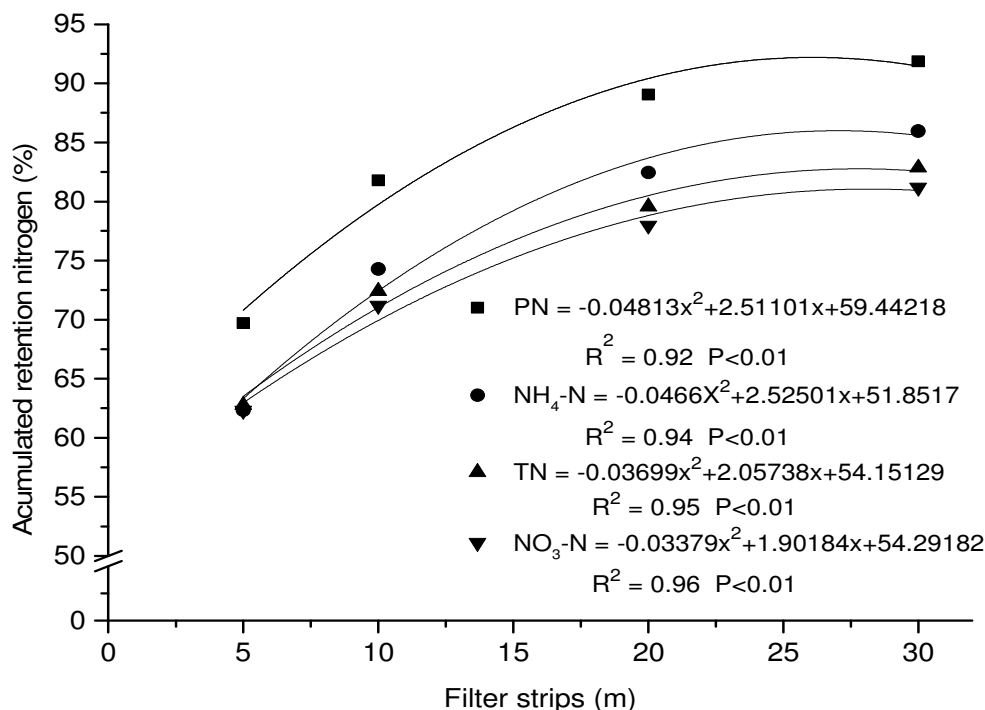


Fig. 3. Retention of accumulated TN (total nitrogen), NH₄-N (ammonium-nitrogen), NO₃-N (nitrate-nitrogen) and PN (particulate nitrogen) at different widths of vegetative filter strips

Table 4. Weighted average concentration of sediment and nutrients in two hours of simulated runoff in vegetative filter strips

VFS m	TS g L ⁻¹	TN mg L ⁻¹	NH ₄ -N mg L ⁻¹	NO ₃ -N mg L ⁻¹	PN mg L ⁻¹	TP	SP	PP	BP
5	1.70	134.71	25.54	101.19	8.70	44.23	27.42	16.55	30.92
10	1.61	125.69	21.55	97.94	6.39	39.12	22.71	16.21	27.37
20	1.54	117.28	18.19	94.80	4.70	34.60	18.81	15.88	24.23
30	1.49	112.62	16.47	93.02	3.92	32.21	16.84	15.68	22.56
IC	3.22	227.6	40.9	170.3	16.3	62.7	31.4	31.3	46.9

IC, initial concentration in the simulated runoff; VFS, widths of vegetative filter strips; R, runoff; TS, total solids; TN, total nitrogen; NH₄-N, ammonium-nitrogen; NO₃-N, nitrate-nitrogen; PN, particulate nitrogen; TP, total phosphorus; SP, soluble phosphorus; PP, particulate phosphorus; BP, bioavailable phosphorus

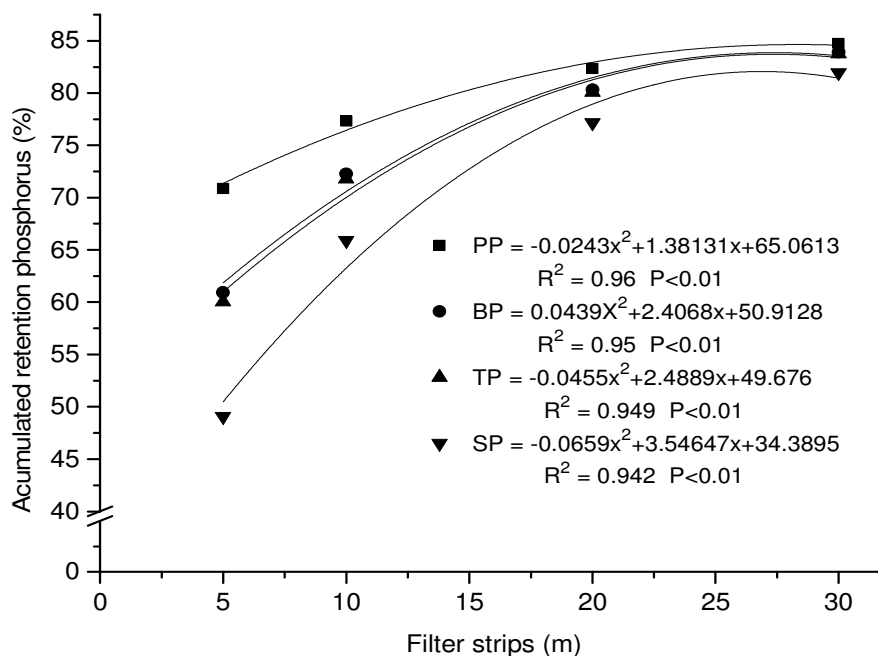


Fig. 4. Retention of accumulated TP (total phosphorus), SP (soluble phosphorus), PP (particulate phosphorus) and BP (bioavailable phosphorus) at different widths of vegetative filter strips

4. CONCLUSION

All VFS widths tested were effective at retaining water, sediment and nutrients with accumulated retention of at least 36, 66, 63, 62, 62, 70, 60, 49, 77 and 61% for water, sediment, TN, NH₄-N, NO₃-N, PN, PP, SP, PP and BP, respectively. The sediment and nutrient retention were highest in the 30 m strips; however, in practical terms, considering the high retention efficiency (on general above 70%) and the economy of arable land, the 10 m filter strip populated by grasses could be recommended to mitigate surface water impacts from runoff coming directly from agricultural fields in sandy clay loam soils with a 10% slope.

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Competing interests

Authors have declared that no competing interests exist.

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