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Nutrient removal effectiveness by riparian buffer zones in rural temperate watersheds: The impact of no-till crops practices

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ABSTRACT

Riparian buffer zones have the potential to capture chemical contaminants and to mitigate detrimental side-effects in aquatic ecosystems derived from excess fertilizers used in agro-food production. No-till farming systems are well known agricultural practices and are widely used in temperate areas. In that regard, different settings and widths of riparian buffer zones (12, 24, 36, 48 and 60 m) with woody vegetation, shrubs or grasses were assessed. The methodology was comprised of the evaluation of a large number of experimental sites and the sampling was conducted after the first rain period and respective fertilizer applications. The results point to the fact that effectiveness is largely controlled by buffer zone width and vegetation type. Indeed, buffer zones with 60 m width composed of woody soils were more effective in phosphorus (99.9%) and nitrogen (99.9%) removal when compared to shrub (66.4% and 83.9%, respectively) or grass vegetation (52.9% and 61.6%, respectively) areas. Woody vegetation has deep rooting systems and woody soils have a higher content of organic matter when compared to grass and shrubs areas.

1. Introduction

Technological advances in the agricultural sector have improved global food and fibers production. However, the leaching of nutrients from fertilization practices is one of the leading causes of the degradation of current aquatic ecosystems (Groffman et al., 2002; Gunningham and Sinclair, 2005). In temperate and subtropical zones the problems are intensified because increasing fertilization processes are required (Syversen and Borch, 2005; Reynolds-Vargas et al., 2006). Indeed, these soils are exposed to long periods of weathering, which results in nutrient-poor soils with little organic matter, low-capacity cation-exchange, high in iron and aluminum oxides with a slightly acid pH (Theodoro and Leonardos, 2006). No-till cropping system is a conservation farming technique in which the planting is done without the steps of conventional tillage plowing and harrowing (Humberto et al., 2011) and has been advocated because it favors the increase in nutrients levels, particularly in the soil surface layer (Schröder et al., 2004; Syversen, 2005). This system always keeps the soil covered with growing plants and plant residues. The coverage is intended to protect the soil from the impact of raindrops, runoff and erosion from water and wind (Schröder et al., 2004). Due to the drastic reduction of erosion, the potential for contamination of the environment offers the largest farmer income. This is because the stability of production is enlarged compared to traditional methods of soil management (Bertol et al., 2005; Humberto et al., 2011).

In order to address this risks of surface water and groundwater contamination by nutrient rich waters, riparian buffer zones have been extensively prescribed. Indeed, these natural engineering systems protect river banks from erosion and may capture water contaminants by physical, chemical and biological processes (Dillaha et al., 1989; Ahola, 1990; Syversen, 2002, 2005; Hefting et al., 2005; Stutter et al., 2009). The use of riparian buffer zones in large areas with intensive agriculture as a mitigation measure for nutrient removal has been questioned primarily due to the existence of few studies addressing the removal effectiveness from agricultural leachates in soil layers of riparian vegetation. This is notable in south-American agricultural regions (Stutter et al., 2009; Ruschel et al., 2009). In addition, most have been conducted by targeting runoff after coordinated simulated flow events using

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artificial rain. Simulations were not conducted using natural or real conditions (Sharpley et al., 1986; Mcdowell et al., 2007).

Therefore, knowledge about the performance in full-scale buffer zones located in tropical and warm-temperate areas is scarce. The objective of this study is to evaluate the contaminants removal capacity of the riparian buffers associated with no-till cropping in temperate climates. We further intend to provide efficient designs for management of agricultural zones and conservation of aquatic ecosystems.

2. Materials and methods

2.1. Characterization of the study area

The river Cará-Cará is located in the southeastern portion of Ponta Grossa, in Paraná state of Brazil (Fig. 1). The Cará-Cará river is a tributary of the Tibagy river, which has a drainage area of 73 km^2 and is part of the Tibagy river basin (Fig. 1).

The main agricultural use in the Cará-Cará river basin is primarily for tillage crops; specifically corn and soybeans. Therefore, representative locations selected in the present study had the same soil characteristics, oxisols, with a percentage of 30% clay and high permeability, and 8–9% slope (Ponta Grossa, 2012). The annual rainfall is about 1650 mm and the average annual temperature 18 °C (±2) (Fig. 2). The climate of the study area is classified as temperate climate (Cfb) according to the Köppen classification (Ponta Grossa, 2012).

According to Fig. 2, corn and maize cropping utilized in the study area followed these steps: Crop > Fallow > desiccation and planting > Growth > Crop > Fallow. The soil was manipulated only at planting time, when a furrow was opened to deposit seeds and fertilizers. This cultivation method is very important for the success of crop rotation, providing nutrient conservation and contributing to pests, diseases and weeds control (Stutter et al., 2009). It is worthwhile to note that the Brazilian Forestry Code prescribes that all farms must leave a riparian zone space between agriculture and the riverbank (Brasil, 2012). The riparian zone must be at least 15 m for rivers and up to 10 m wide. For rivers with widths larger than 10 m, the recovery should occur in sites corresponding to half the width of the river, subject to a minimum of 30 m and a maximum of 100 m.

2.2. Methods of sampling

A total of 27 study sites were selected with riparian buffers having approximate widths of 12, 36 and 60 m. Nine sites were established for each of three different dominant vegetation types: woodland, shrubs and grasses, containing a triplicate transept for each width (12 m, 36 m and 60 m). The woody vegetation is characterized as alluvial rain forest, with a predominance of trees with a height range of 15–20 m. The predominant species are: *Sebastiania commersoniana*, *Anadenanthera colubrina, Vernonia discolor, Jacaranda puberula, Syagrus romanzoffiana, Ilex theezans, Ocotea porous Ocotea odorifera, Cedrela fissilis* and *Tabebuia alba*. The shrubby plants are small with a maximum height of 3 m. The predominant species are: *Miconia sellowiana, Miconia hyemalis, Erythroxylum microphyllum* and *Petunia rupestris*. Among the grasses, the most common genera are Andropogon and Aristida, especially represented by *Aristida pallens*, *Chloris bahiensis* and *Andropogon bicornis*. The latter is considered a colonizing species of degraded areas (Ruschel et al., 2009). In each study site, transepts were established between the crop limit and the river channel. Water was collected from piezometers with a ground water level of 3–4 m. The sampling wells were made with drilling machines and a Dutch auger.

Sampling was performed four times following crop phenology and the crop events of nutrient applications (Fig. 2), giving a population of 12 values ($n = 12$). Water sampling was performed following the first rain period and after applications of nitrogen, phosphorus and potassium fertilizers (Fig. 2). Sampling occurred during periods of rain and drought with two samplings per year during the rainy season (March and April 2013/2014) and two samplings per year in the dry season (May and June 2013/2014). Rainfall ranged from 25 to 74 mm in the rainy season and 27–55 mm in the dry season (Fig. 2). Water was removed using a vacuum pump, and after each collection the pump and tubes were cleaned with distilled water. The first 500 mL of water was discarded before each sample in order to obtain representative samples.

2.3. Analysis

The values of the physical–chemical parameters dissolved oxygen, electrical conductivity, pH, oxidation–reduction potential, salinity, temperature and depth were determined in situ using a multi-parameter AP-7000 AquaProbe. All samples were stored in polypropylene bottles and preserved at 4 °C for further analysis in the laboratory. In addition, the samples were comprised of nitrogen (N), nitrates (NO_3^-), nitrites (NO_2^-), phosphorus (P) and potassium (K^+). They were also tested for alkalinity, as well as hardness, free carbon dioxide (CO_2), carbonates (CO_3^{-2}), chlorides (Cl^-), fluoride (F^-), sulfate (SO_4^{-2}), calcium (Ca^{+2}), magnesium (Mg^{+2}), sodium (Na^+) and dissolved silica (SiO_2). Analyses were performed according to Standard Methods (APHA, 2012). For quality control, analytical reagents provided by Sigma Aldrich were used with a purity of 99.9%. 30 samples were also collected in duplicate and analyzed by an independent laboratory to confirm the results.

The significance of different samples was tested by analysis of variance (ANOVA). When results were shown to be significant, Tukey's multiple comparison tests were run to determine which buffer zone width were significantly different by least significant difference (LSD) at the 5% level using the Origin Pro 9.0 (OriginLab Corporation, USA) and Statistic (Version 10, StatSoft, USA).

2.4. Runoff determination

Runoff sampling was performed using study plots with 2 m wide and 5 m in length, where the area of each experimental plot had 5 m^2. The samples were enclosed by sheet-metal of 10 cm height and 5 cm buried in the ground. The plots were allocated following the slope being the lower end, the last one meter built in a "V" formation where the flow was channeled to a bucket. The average accumulated rainfall was measured with the use of a portable weather station Vantage Vue Davis, installed near the study area. The volume of water was calculated according to the area of the experimental plot, with the percentage of retained (or infiltrated) water calculated as the difference between the volume of the plot and the volume of runoff collected.

3. Results

The results obtained in the different study periods (March–June 2013 and 2014) showed no significant differences, thus the data were used together. There were no significant differences ($p > 0.05$), using Tukey's test, between the different sampling points regarding nitrites (NO_2^-), potassium (K^+), alkalinity, hardness, free carbon dioxide (CO_2), carbonates (CO_3^{-2}), chloride (Cl^-), fluoride (F^-), sulphates (SO_4^{-2}), calcium (Ca^{+2}), magnesium (Mg^{+2}), sodium (Na^+) and dissolved silica (SiO_2). In addition, these elements were within the typical values for the region (Zimmermann et al., 2008).

Table 1 shows the nutrient concentrations from the samples collected at 12 m, 36 m and 60 m after the agricultural zone,

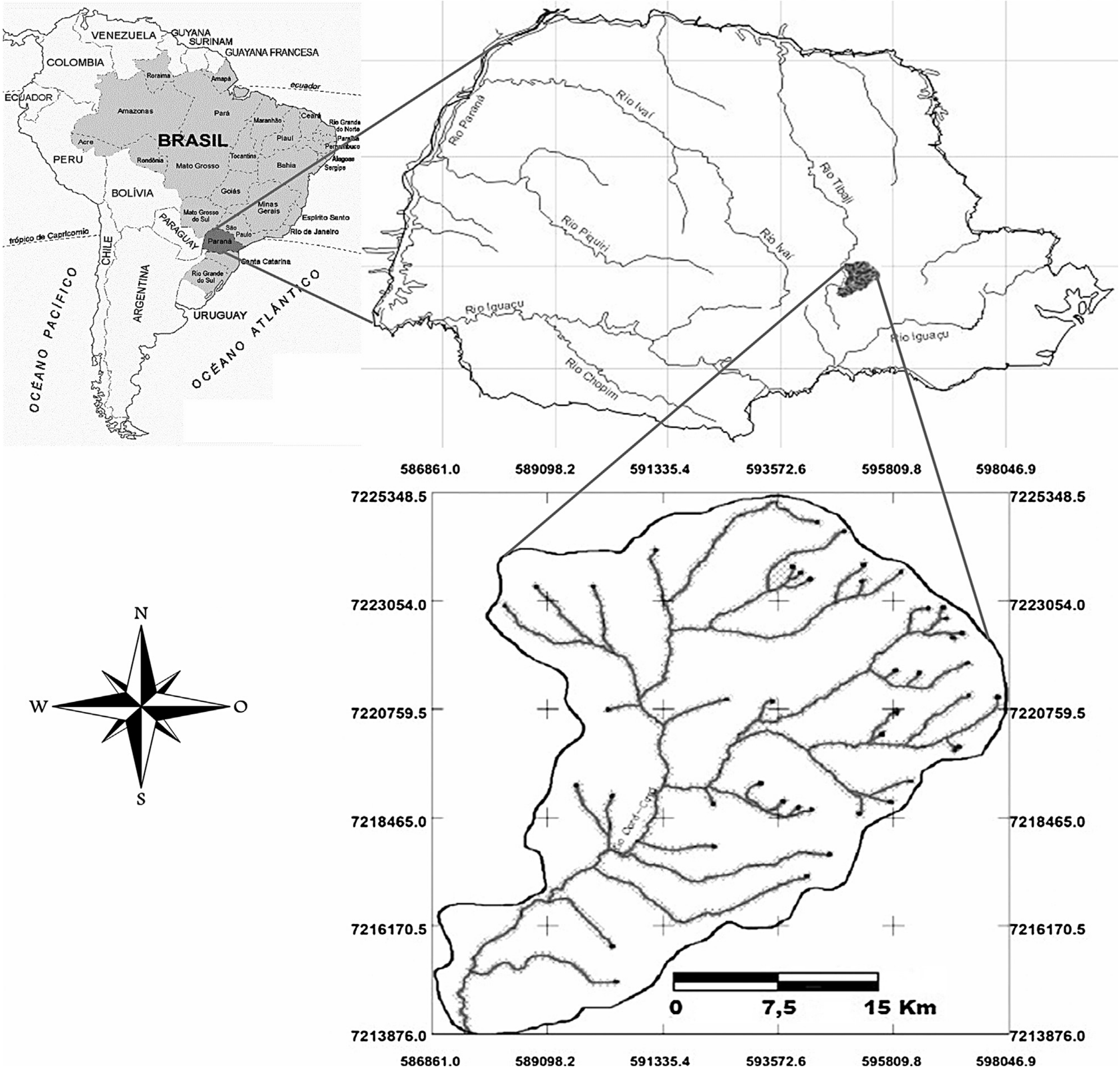

Fig. 1. Map of Cará-Cará river watershed.

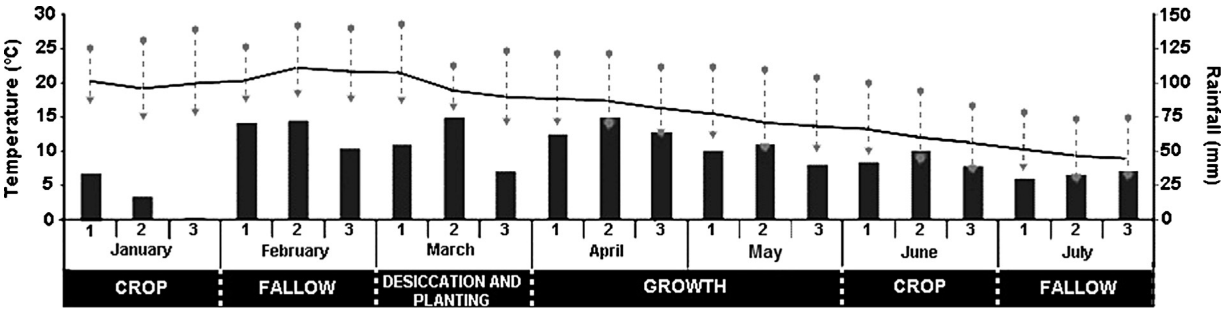

Fig. 2. Temporal evolution of the corn plantation in no-till systems; temperature and rainfall, every ten days. * Maximum Temperature; — Medium temperature; ▲ Minimum temperature. Vertical bars indicate rainfall.

in regions composed by woody vegetation, shrubs and grasses, separately. In the buffer zone composed of woody vegetation, the removal of N, P and NO_3^- were significantly higher than in areas with grasses and shrubs. For the other nutrients, no significant differences were observed between the buffer zones (Table 1). Using the Tukey analysis it was possible to compare the averages of local width of 12 m, 36 m or 60 m, composed of grasses (shrubby or woody). All areas composed of grasses, shrubby or woody showed

Table 1
Average values and range for the chemical parameters obtained at three different riparian vegetation structures and widths (12, 36 and 60 m), $n = 9$. Averages were calculated using data collected in triplicate for four sampling periods.

Parameters	Woody			Shrub			Grasses		
	12 (m)	36 (m)	60 (m)	12 (m)	36 (m)	60 (m)	12 (m)	36 (m)	60 (m)
N (mg L^{-1})	23.6 (±2.0)^{d}	2.55 (±0.2)^{e}	0.03 (±0.06)^{a}	25.0 (±1.3)^{d}	11.4 (±0.8)^{e}	6.9 (±0.7)^{a}	32.0 (±1.4)^{d}	30.3 (±1.8)^{e}	16.1 (±2.5)^{a}
P (μg L^{-1})	13.9 (±0.5)^{f}	1.7 (±0.4)^{g}	0.03 (±0.02)^{b}	18.8 (±0.8)^{f}	13.8 (±0.7)^{g}	4.0 (±0.6)^{b}	23.4 (±0.9)^{f}	23.5 (±0.7)^{g}	15.1 (±0.8)^{b}
NO_3^- (mg L^{-1})	13.8 (±0.5)^{h}	2.3 (±0.6)^{i}	0.008 (±0.01)^{c}	23 ± (1.5)^{h}	15.3 (±0.7)^{i}	7.9 (±1.1)^{c}	31.9 (±1.7)^{h}	25.1 (±1.4)^{i}	19.2 (±0.8)^{c}
NO_2- (mg L^{-1})	0.2 (±0.1)	0.2 (±0.1)	0.1 (±0.1)	0.05 (±0.05)	0.09 (±0.05)	0.02 (±0.01)	0.2 (±0.1)	0.1 (±0.1)	0.09 (±0.04)
K^+ (mg L^{-1})	0.4 (±0.3)	0.6 (±0.3)	0.4 (±0.3)	0.6 (±0.4)	0.6 (±0.4)	0.5 (±0.4)	0.5 (±0.3)	0.7 (±0.3)	0.4 (±0.3)
Mg^{2+} (mg L^{-1})	2.4 (±0.2)	2.5 (±0.2)	2.5 (±0.3)	2.3 (±0.2)	2.7 (±0.2)	2.5 (±0.2)	2.1 (±0.1)	2.4 (±0.1)	2.3 (±0.2)
Ca^{+2} (mg L^{-1})	4.0 (±0.7)	4.1 (±0.6)	4.2 (±0.3)	3.9 (±0.8)	4.1 (±0.8)	4.1 (±0.5)	3.6 (±0.6)	4.0 (±0.8)	3.9 (±0.4)
pH	5.0 (±0.2)	4.9 (±0.2)	5.1 (±0.2)	4.8 (±0.5)	4.9 (±0.2)	5.2 (±0.3)	4.5 (±0.5)	4.7 (±0.1)	4.9 (±0.3)

a–i: Results obtained for the areas containing grasses and shrubby showed significant difference by Tukey test ($p < 0.05$), compared to area composed by woody and same width.

significant differences ($p < 0.05$) for the concentrations of N, NO_3^- and P comparing the same buffer zone widths. For NO_2-, K^+, Mg^{2+}, Ca^{+2}, and pH were no significant differences observed in different buffer zones composition but the same width.

Regarding nitrogen (N), phosphorus (P), and nitrates (NO_3^-), significant differences were found ($p < 0.05$), between different distances of the agricultural area (Fig. 3).

Fig. 3 shows the distribution of the values of efficiency removal for N, P, and NO_3^- grouped into vegetation types from a range of widths (12, 36, and 60 m). The efficiency values were obtained by relating the analyzed data for concentration points with the concentration at the zero point. For a vegetation strip of 60 m (Fig. 3), the woody vegetation obtained a retention capacity of 100% for N, P and NO_3^-. The shrub vegetation obtained 83% for removal of N, 66% for P and 80% for NO_3^-. In the grass buffers, there was retention of 61% for N, 53% for P and 52% for NO_3^-. For the vegetation strip of 36 m (Fig. 3), woody vegetation was efficient in removing 93% N, 92% P and 94% of NO_3^-. The N removal efficiency when the shrub vegetation was present in the buffer zone was 56% for P, and 46% to 61% for NO_3^-. However, when the buffer zone consisted of grass, there was a removal power of 41% for N, 34% for P and 37% for NO_3^-. In the range of 12 m (Fig. 3) the effective removal for woody vegetation was calculated at 43% for N, 36% for P and 65% for NO_3^-. For the shrub vegetation, the removal efficiency was 41% for N, 32% for P and 42% for NO_3^-. In the grass area, removal efficiency was 21% N, 17% P and 20% NO_3^-.

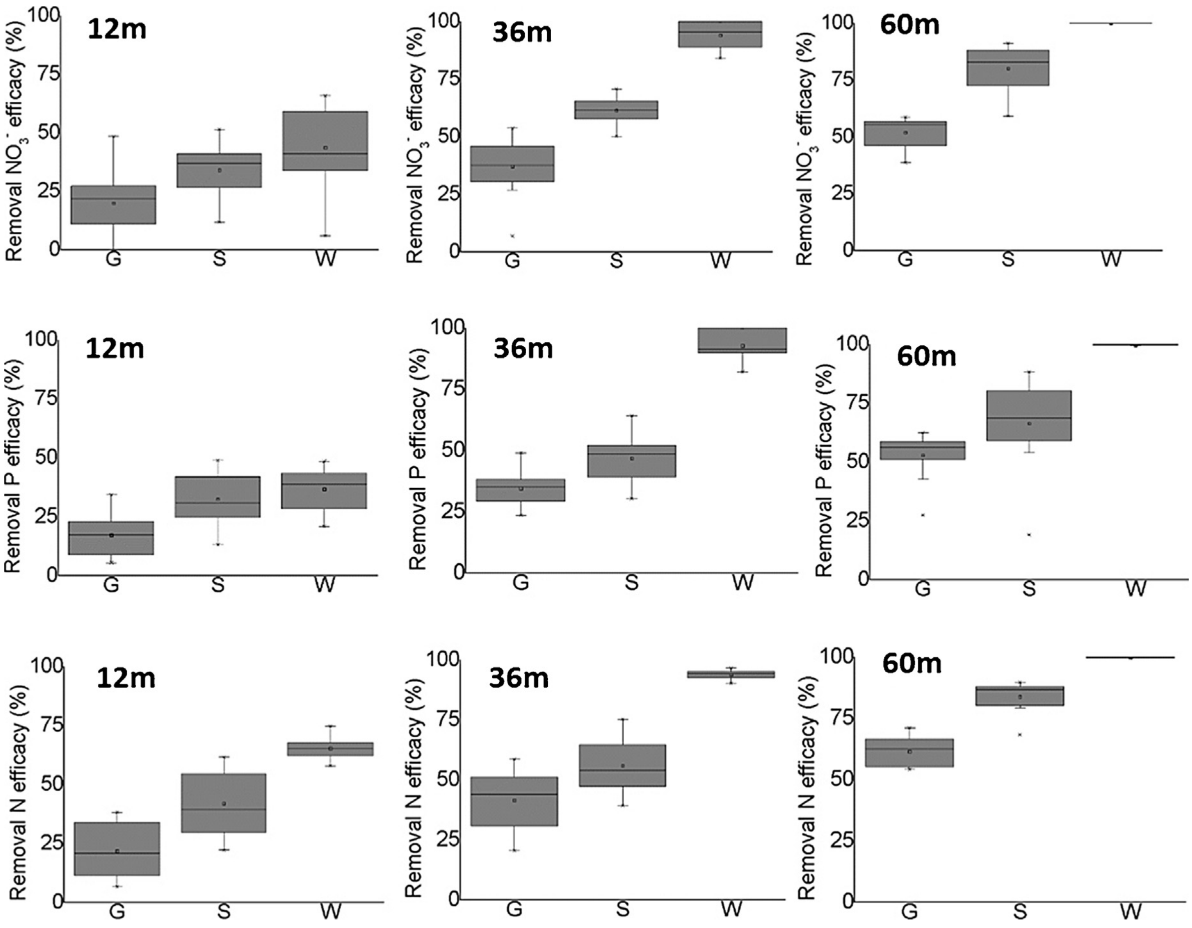

Fig. 3. Removal of N, P and NO_3^- in each study area, where N (nitrogen), P (phosphorus) and Nit (nitrate), S (shrub), G (grasses) and R (woody vegetation). The efficiency was calculated in the following buffer zone widths (A) 0–12 m (B) 0–36 m, and (C) 0–60 m.

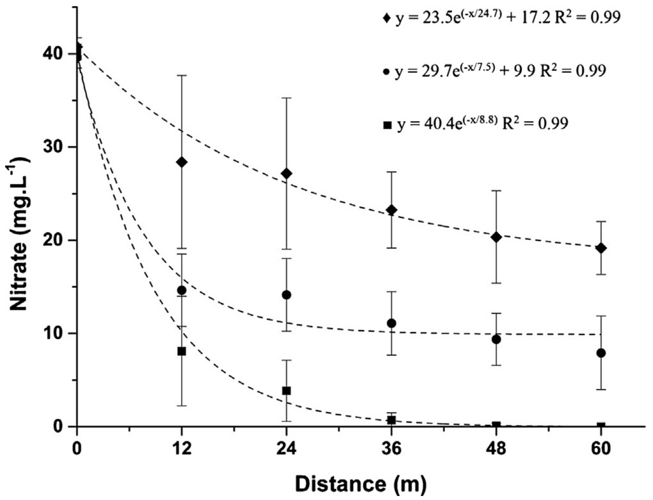

Fig. 4. Relation between nitrate concentration (mg L^{-1}) and the distance of the sampling points in the buffer zones, using widths between 0 and 60 m. Nitrate concentration was measured in areas with buffer zone composed of ♦ Grasses, ● Shrub or ■ Woody.

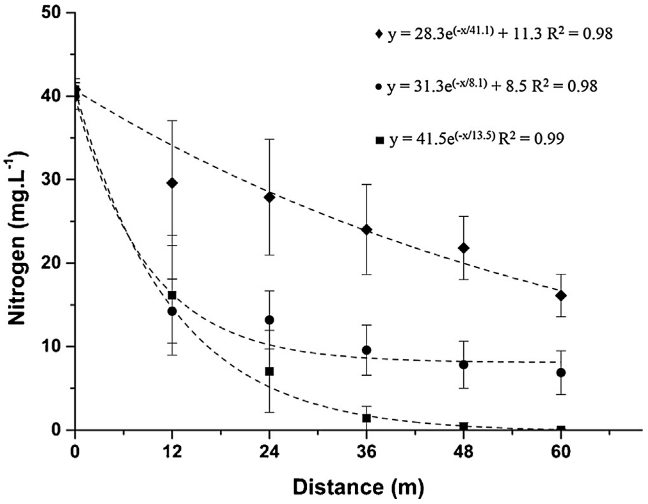

Fig. 5. Relation between the concentration of nitrogen (mg L^{-1}) and the distance of the sampling points in the buffer zones, utilizing widths between 0 and 60 m, where the zero point is after 60 agriculture and the river. Nitrogen concentration was measured in areas with buffer zone composed of ♦ Grasses, ● Shrub or ■ Woody.

Vegetation strips with 60 m width obtained the best removal efficiency of all vegetation types studied, especially for nitrogen. There was a significant reduction of the nutrients using Tukey's test. For the woody vegetation, removal reached in 100% with a 60 m buffer zone. Comparing the removal obtained for buffer zones of different composition and different widths, the N, P and NO_3^- showed significant differences for removal obtained in buffer zones of 60 m, composed of grasses, shrubby and woody vegetation. The lowest filtering effect was observed for the buffer zone composed of grasses, both for N, P and NO_3^-, where removal after 60 m were only 62% and 52%, respectively.

The relation between nitrate concentration and distance to the crop in areas with a buffer zone of 60 m can be observed in Fig. 4.

The buffer zone composed by grasses showed a maximum 52% removal of nitrate, keeping a minimum concentration of 19 mg L^{-1}. For grasses buffer zone (Fig. 4), the correlation coefficient (R^2) was 0.99 for exponential decay regression. The analysis of variance (ANOVA) showed significant ($p < 0.05$) differences only between the initial and final points of collection. The values obtained for the samples collected at the point of 12 m to 60 m showed no significant difference ($p > 0.05$). In the buffer zone composed of shrubby vegetation (Fig. 4), the maximum nitrate removal observed was 80%, with a minimum concentration of nitrate at 10 mg L^{-1}. The R^2 was 0.99. The analysis of variance (ANOVA) showed significant differences ($p < 0.05$) to the nitrate concentration between the start and end points of collection. When the buffer zone analyzed was composed of woody vegetation (Fig. 4), the nitrate removal reached 100% when 60 m away from the agricultural zone, and the correlation coefficient (R^2) of the exponential equation was 0.99. From the results was possible to determine the nitrate removal in buffer zone composed of grasses, shrubby and woody (Fig. 4) adjusted by an exponential decay equation. Hence, nitrate removal efficiency increases with the width of the buffer zone and the complexity of the vegetation structure.

Similar analyzes were performed regarding the concentration of nitrogen (Fig. 5). For buffer zones consisting of grasses, the minimum concentration of nitrogen observed was 15 mg L^{-1}. For buffer zones consisting of shrubby vegetation the minimum was 4 mg L^{-1} and for woody vegetation, the removal was 100%.

The analysis of variance (ANOVA) showed significant differences ($p < 0.05$) to the concentration of nitrogen between the start and end points of collection for shrubby and woody vegetation. For grasses, no significant differences were observed ($p > 0.05$) between 12 m and 60 m collected samples. For grasses and shrubby, the R^2 was 0.98, for woody the R^2 was 0.99. The nitrogen removal in buffer zone composed for grasses, shrubby and woody is shown in Fig. 5.

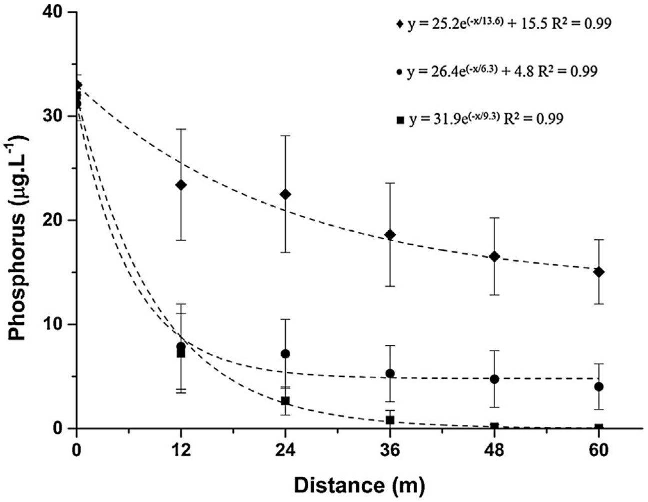

Fig. 6. Relation between phosphorus concentration (μg L^{-1}) and the distance of the sampling points in the buffer zones, utilizing widths between 0 and 60 m, where the zero point is after 60 m agriculture and the river. Phosphorus concentration was measured in areas with buffer zone composed of ♦ Grasses, ● Shrub or ■ Woody.

For the analysis of phosphorus (Fig. 6), when the study area was composed of grasses, the minimum concentration observed was 12 μg L^{-1}. When the buffer zone consisted of shrub vegetation, a lower phosphorus concentration of 4 μg L^{-1} was observed. For the woody buffer zone, no phosphorus concentration was observed after 60 m. The analysis of variance (ANOVA) showed significant differences ($p < 0.05$) to the concentration of phosphorus between the start and end points of collection for grasses, shrubby and woody vegetation.

In all the cases, the relation between phosphorus concentration reduction in the buffer zone composed for grasses, shrubby and woody is proportional to an increase in the width of the buffer zone. The removal of nitrogen, nitrate and phosphorus increases in the following order: grasses > shrub vegetation > woody vegetation. The buffer zone consisting of woody vegetation was more efficient in removing nitrate, phosphorus and nitrogen residual present in groundwater originated from the agricultural areas, as opposed to non-woody riparian zones. In this work, a nitrate removal of 98% was observed with the same width of woody vegetation. A significant difference ($p < 0.05$) between the points of grass, shrubs and woody vegetation for the NO_3^- was noticed. In the 36 m buffer zone composed of woody vegetation, removal was 98% greater than that observed for shrub (72%) and grass (42%). Buffer zones consisting of grass or shrub presented a retention performance smaller than the buffer zone composed of woody vegetation and the riparian zone showed the lowest runoff. The values ranged from 2.7 to 5.4% cumulative retention of rain water and higher runoff capacity subsurface, reaching 94.5% (±0.9) infiltration. The region composed of shrub presented a runoff retention of 9.3% (±2.3) and sub-surface infiltration of 90.7% (±2.1) The region composed of grasses had the highest runoff, reaching 14.2% (±3.4) retention and less infiltration with 85.8% (±2.6).

4. Discussion

The woody vegetation zone has a higher nutrient retention capacity (99.9%). Soils with such vegetation have a higher content of organic matter when compared to areas of grass and shrubs, due to leaves and wood that are deposited and degraded in the soil (Young et al., 1980; Groffman et al., 2002). The organic matter has good nutrient adsorption characteristics due to a complex system of carbonic substances and processes of humus stabilization (Cahn et al., 1992). The soil and woody vegetation ecosystem contains a rich microbial population (Groffman et al., 2002). The areas of woody vegetation have a deep rooting system that reaches the saturated soil zone and removes nitrogen compounds (Groffman et al., 2002; Mayer et al., 2007). The riparian vegetation consisting of woody vegetation also showed a reduction in P concentration and nitrogen. This reduction can be explained by the high sediment retention and high concentration of organic matter to where the P and nitrogen can be adsorbed (Sharpley et al., 1994; Mankin et al., 2007; Mcdowell et al., 2007; Stutter et al., 2009).

The results obtained for runoff corroborate the results obtained for nutrient removal. In regions with riparian vegetation composed of trees, the infiltration rate is higher and erosion is lower. Because the soil is protected by trees and related biomaterial, the water drops impact in the soil is reduced and the higher infiltration rates hinder the transport of nutrients through runoff. However, in regions composed of grasses, the impact of rain on unprotected soil causes a greater nutrient runoff dragging toward the river. Areas of study composed of shrubs had an intermediate pattern.

The removal capacity in buffer zones of 60 m allowed the removal of all chemical elements up to non-detectable levels. Similar results were observed (Lee et al., 2000) when evaluating the ability of different species of riparian vegetation for nutrient retention. For nitrate, however, the same authors observed that woody vegetation with 20 m width had a good capacity for removing pollutants, with an efficiency of 65%. The riparian zone composed of shrubs and grasses did not obtain good results when compared with areas composed of woody vegetation (Young et al., 1980; Mankin et al., 2007). Areas comprised of grasses and shrubs have a small amount of organic soil matter (<4.5%) and lower microbial activity due to the lack of shade and vegetable scraps. Thus, the soil remains unprotected, which increases the surface runoff, thus increasing the sediment transport. Hence, the contact time between pollutants, vegetation and soil is lower, increasing the area of dispersion of pollutants, especially of P that is transported by sediment and adsorbed by the surface charges of clay minerals and organic matter (Sharpley et al., 1994).

The adoption of no-till system, affects the dynamics of P and N in the soil, mainly due to the lack of soil disturbance and excess organic matter that increases the contact between the colloids and the ions P and N, increasing the adsorption, favoring processes of mineralization and nitrification (Cahn et al., 1992; Chen and Hong, 2011). These conditions, combined with short rainfall, but with strong intensity in the study area and a large excess nitrogen and phosphorus, lead to the accumulation of nitrate and high losses by subsurface leaching (Groffman et al., 2002; Chen and Hong, 2011). Numerous studies have shown that yield from agriculture does not increase significantly when high rates of fertilizer application exceeds a certain value, however contamination and residual nitrate and nitrogen increases sharply in the saturated soil zone (Syversen, 2002; Schröder et al., 2004; Hefting et al., 2005; Grismer et al., 2006; Chen and Hong, 2011). In the study area used in this work, the nitrogen (42 mg L^{-1}) and nitrate (44 mg L^{-1}) were the main contaminants of the saturated soil zone. Concentrations of nitrate and nitrogen had a good reduction for riparian zone composed of woody vegetation, with 36 m width, reaching 3 mg L^{-1} and 1 mg L^{-1}, respectively. Considered the nutrients studied, nitrate is the nitrogen most stable form which is more significant in terms of water resources contamination and human health. For instance, regarding Brazilian (Brasil, 2011) and USA legislation (EPA, 2009) both suggest a maximum concentration of 10 mg L^{-1} of $N—NO_3$ Thus the riparian vegetation composed of woody with a width of 36 m were appropriate to prevent surface and ground water contamination. A higher nitrogen and nitrate removal rate in riparian areas was also reported by other researchers (Borin et al., 2005; Hefting et al., 2005; Lovell and Sullivan, 2006).

Other studies in Europe and the United States had similar results despite the different climatic conditions (Wenger, 1999; Borin et al., 2005; Hefting et al., 2005). These authors pointed out that widths smaller than 10 m provide only a limited protection against the nitrate contamination of water resources. Therefore, riparian vegetation consisting of woody vegetation with a width higher than 36 m seem to be the minimum necessary for the maintenance of biological components responsible for the removal of micropollutants. This includes both soil and water in the saturated zones in temperate climatic areas and oxisols where the ability of the soil to retain substances was studied (Groffman et al., 2002). According to the authors, the organic substances in the soil have ability to connect and retain anions by having amino groups, peptide bonds, and other nitrogenous polypeptides. These anions, connected directly or through metals in the case of phosphates, are easily assimilated by plants. Thus, the soils of areas with woody vegetation, which are characterized by a high content of organic matter are deposited in the soil. They continue to form humic substances, which are also derived from the decomposition of organic matter.

The technique of cultivation and soil management also exerts great influence on the quality of surface and groundwater (Robertson et al., 1991). Some agricultural practices are capable of causing widespread nutrient contamination or other agricultural contaminants, particularly in areas of thin grounds, with good drainage (Muscutt et al., 1993; Uusitalo and Jansson, 2002; Gharabaghi et al., 2006). In this work, the no-till system showed excellent results by reducing runoff and the concentration of nitrogen, nitrate and phosphorus from areas between agriculture and the points of the study. This decline was observed in the areas of woody vegetation, shrub and grass.

5. Conclusion

The relation between the removal efficiency of agricultural nutrients by riparian buffer zones and their main characteristics in no-till systems and temperate zones was presented. Buffer width is an important factor in the removal of all pollutants, especially N,

NO_3^- and P. The widths of 12 m had an inadequate protection for the concentration of nutrients used in the study sites. Regarding the type of vegetation, buffer zones composed of trees have a very effective removal rate of N, P and NO_3^- compared with areas of arborous vegetation and grass. The results indicate that the design of riparian buffer zones should be conservative. The higher efficiency of woody vegetation zones of 36 m and 60 m widths, combined with agricultural economy, presents a greater potential for acceptance by rural producers, thereby facilitating the diffusion of this conservation practice in agriculture. Furthermore, the width of 36 m was appropriate to reduce the nitrate concentration to levels below the required values (levels) defined in the water protection legislation and regulatory standards.

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