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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,