Science of the Total Environment 598 (2017) 188–197

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Differences in nitrate and phosphorus export between wooded and grassed riparian zones from farmland to receiving waterways under varying rainfall conditions

Amanda D. Neilen *, Chengrong R. Chen, Brett M. Parker, Stephen J. Faggotter, Michele A. Burford

Australian Rivers Institute, Griffith School of Environment, Griffith University, Kessels Rd, Nathan, Queensland, 4111, Australia

HIGHLIGHTS

- Woody vegetation reduced phosphorus, but not nitrogen leaching.
- Nitrogen leached from soils was controlled by two different drivers, dependent upon rainfall.
- Under low rainfall, soil microbes were important in reducing nitrogen leaching.
- Denitrifying microbes appeared to be limited by carbon availability.
- During high rainfall, grass cover was important in reducing nitrogen leaching.

ARTICLE INFO

Article history:
Received 28 November 2016
Received in revised form 4 April 2017
Accepted 9 April 2017
Available online 22 April 2017

Editor: Jay Gan

Keywords:
Watershed
Water quality
Nitrate
Leaching
Structural equation modelling
Landsat
Buffer strips

ABSTRACT

Agricultural activities in catchments can cause excessive nutrient loads in waterways. Catchment nitrogen (N) and phosphorus (P) flows may be intercepted and assimilated by riparian vegetation. While prior studies suggest that woody vegetation is preferable for reducing P loads, the question remains: is woody vegetation or grass cover more effective at reducing catchment N and P exports to waterways. To address this we investigated the relative importance of vegetation type, hydrologic and soil microbial processes on N and P losses from soil to a stream. The study involved the analysis of data from two soil microcosm experiments, and a field case study. We found P leaching loss from riparian zones depended significantly on vegetation type (woody vs. grass cover), with lower P exported from wooded riparian zones, irrespective of the scale of rainfall. For N leaching losses, the scale of rainfall had an effect. During high rainfall, vegetation type had a major effect on N leaching loss, with lower N exported from grassed verses wooded riparian zones. However, under low rainfall conditions, soil type and soil C and N stores, potential indicators of soil microbial activity, rather than vegetation cover, affected N leaching. It is hypothesized that soil microbes were reducing N removal under these conditions. We reason that nitrifiers may have played an important role in soil N cycling, as increased soil ammonium had a strong positive effect on nitrate leaching loads, mediated through soil nitrate stores. Whereas, N immobilization, via incorporation into microbial biomass, and denitrification processes appeared to be limited by C availability, with increased C associated with reduced N leaching. Overall, this study identified that N leaching losses from riparian zones appeared to be affected by two different processes, vegetative uptake and soil microbial processes, the relative importance of which was driven by hydrological conditions.

1. Introduction

Agricultural landscapes are often denuded of natural vegetation and receive high inputs of nitrogen (N) and phosphorus (P) to boost the productivity of soils. These nutrient inputs affect soil N and P:carbon (C) ratios, which have repercussions for soil biogeochemical processes, and subsequently affect nutrient exports to receiving waterways. To mitigate these nutrient loads to waterways, riparian vegetation buffers are planted or protected along the banks of low-order streams (Collins et al., 2013; Lyons et al., 2000).

The biogeochemical processes responsible for producing, transporting and retaining N and P are a product of four catchment features – vegetation cover type, soil microbial community, geology and hydrology (Harris, 2001). In the case of N, greater N reduction efficiencies have been reported from woody riparian buffers compared to non-

* Corresponding author.
E-mail address: amanda.neilen@griffithuni.edu.au (A.D. Neilen).

http://dx.doi.org/10.1016/j.scitotenv.2017.04.075

woody vegetation (e.g. Peterjohn et al., 1984; Hefting et al., 2005). This is based on the premise that woody vegetation: (1) reduces catchment subsurface N loads through assimilation by deep roots; (2) has high N storage capacity in the above ground biomass; and (3) has leaf litterfall which increases the soil carbon (C) pool; increasing N immobilization in microbial biomass and enhancing denitrification rates (Fennessy and Cronk, 1997). Non-woody vegetation is defined as grass, forbs and herbaceous species (Lyons et al., 2000) and is potentially less efficient at controlling N losses, due to a relatively shallow root network, and lower above-ground biomass. However, several studies have found no difference in N and C content, and N and C fluxes of pasture vs. forested soils (Gageler et al., 2014; Neilen et al., 2016). This is consistent with field studies that failed to show substantial reductions in N concentrations in streams running through woody riparian buffers (McKergow et al., 2003; Olley et al., 2014).

In the case of P, greater retention (e.g. up to 60%) can occur in riparian zones after reforestation with woody vegetation (i.e. Vellidis et al., 2003). This is attributed to woody vegetation acting as a physical barrier, where it is predominantly the roots of these woody plants can intercept catchment P loads, and prevent them from reaching waterways (McKergow et al., 2003; Miller et al., 2014). However, woody vegetation is not always effective at reducing catchment P loads. For example, woody vegetation is more effective at reducing sediment-born P, than dissolved P loads (i.e. soluble reactive P) (Lowrance et al., 1997). Furthermore, some studies have found no reductions in P loads reaching streams after restoration of woody vegetation along riparian zones (i.e. Newbold et al., 2010).

This variability in findings between studies on N and P highlights the lack of sufficient understanding of the relative contribution of plant assimilation, microbial retention and denitrification processes for N reduction (Correll et al., 1997; Woodward et al., 2009). In some environments, denitrification capacity exceeds N assimilation of plants (Fennessy and Cronk, 1997; Haycock and Pinay, 1993). In these environments, N removal is only limited by the availability of organic C, which is a key substrate for microbial communities (Sobieszuk and Szewczyk, 2006). Carbon is less likely to be limited in soils under woody vegetation due to its high contribution of plant-derived detrital C (Haycock and Pinay, 1993; Hefting et al., 2005), the biomass of which increases with vegetation age (McMillan et al., 2014). However, soils under grass cover often have a shortage of bioavailable dissolved organic C (DOC) relative to reactive N (Mooshammer et al., 2014), which can limit microbial processes (Kopáček et al., 2013). For example, litterfall-covered soils in woody riparian buffers have a higher C:N ratio, in comparison to soil under grass, i.e. 70:1 and 17:1 respectively (Mooshammer et al., 2014; Neilen et al., 2016).

Unlike N, the biological controls on P are minor in comparison to soil binding. This is because P uptake by plants and microbes is a highly energy intensive processes, due to the high sorption capacity of the phosphate ions (Sharma et al., 2013). For example, only 0.1% of P is bioavailable for plant uptake, while the remaining P is rapidly converted into metal-cation complexes and fixed in the soil (Sharma et al., 2013). However, similar to N, soil organic C pools may increase availability of inorganic P to plants and microbes, particularly in soils under woody and grassed areas, in comparison to arable soils (Bünemann, 2015).

N and P leaching from soils in subtropical climate zones is likely to vary from that in temperate zones. Subtropical climates have summer rainfall events, which mean soil wetting occurs during higher temperatures, and in short (minutes to hours' time scale), high volume events. In comparison, many of the studies are done in temperate climates which have rainfall during a cooler period of the year and at a lower volume per day, (e.g. Hefting et al., 2005; Hill, 1996; Peterjohn et al., 1984). Wet-drying cycling in soils increases inorganic-N leaching which is the result of microbial processes transforming previously recalcitrant N (DOM-bound N) into inorganic-N via N mineralization (Venterink et al., 2002). At the same time denitrification rates may decrease. Secondly, a study found negligible interception of catchment runoff N loads by riparian vegetation during rainfall events in humid tropical agricultural landscapes (Connor et al., 2013). Therefore for N, rainfall may override the effect of riparian vegetation in changing the form and quantity of N exported from soils. In contrast, riparian buffer reducing erosion during high rainfall events, can reduce export of sediment-bound P (Lucy et al., 2004; Olley et al., 2014).

This study was designed to determine the relative importance of soil cover (woody vegetation vs. grass), and runoff intensity on N and P leaching losses from riparian zones in a subtropical river system. We also investigate how carbon (C) loads are influenced by soil cover and rainfall, since C levels in soil is a key determinant of soil microbial processes. Specifically, we aimed to (1) identify how N, P and C leaching levels compare between woody and non-woody riparian zones, and (2) identify how N, P and C leaching differ under varying rainfall conditions.

2. Methods

2.1. Site description

The study was undertaken in a small (75 km^2) subtropical catchment, viz. Lake Baroon, located in Queensland, Australia (Fig. 1). It has two streams viz. Obi Obi Creek and Bridge Creek, which flow into Lake Baroon, a drinking water supply. The predominant land uses in the Lake Baroon catchment at the time of the study (2014) were dairy and beef farming, inter-dispersed with forested areas and peri-urban residential blocks. The soils in this area are mostly derived of tertiary basalt flows, classed as a haplic, mesotrophic, red Ferrosols, and for the sites sampled, the soil was determined as a loamy sand (Neilen et al., 2016). Detailed descriptions of this study area are available in Neilen et al. (2016).

There were two experiments aimed at determining how nutrient and C leaching from a Lake Baroon catchment was affected by 1. woody riparian versus grass dominated vegetation, and 2. runoff volume. The first series of experiments focussed on four paired sites in the Lake Baroon catchment, with each pair consisting of four woody riparian vegetation (W), and four grass-dominated vegetation (G) (8 sites × 5 reps, total 40 soil cores) (Fig. 1). The paired G and W sites each had a mean reach length 115 m, and each set of paired sites were located within 1.5 km of each other (Fig. 1). Site selection was based on geology, stream bed slope, stream order and land use (see Laceby et al., in press). Spatial analysis was undertaken to characterize the vegetation cover in the immediate (50 m radius), intermediate (100 m radius), and upstream (200 m radius, extended to headwater location) riparian area (Supplementary material 2). Vegetation classification and buffer analysis output showed some similarities between W and G sites (Table S1).

2.2. Experiment 1 - effect of riparian vegetation type on N, P and C leaching

Soil cores were collected from the four paired W and G sites on 1 and 2 October 2013. Soil cores (dimensions; 4.7 cm internal diameter, 8.0 cm depth) were stored in ambient light at a temperature of 20–24 °C for up to 10 d, until the leaching experiment commenced.

The soil was held within the core by covering the bottom of the pipe with PVC coated fiberglass mesh, secured with a rubber band. Soils were flushed with 90 mL of distilled water to moisten the soil. Leachates were collected after pouring 15 mL of distilled water onto the soil surface at the start of each hour over a 6 h period (total 90 mL) (Table 1). This water volume and rate was chosen to simulate a rainfall rate of 9 mm h^{-1} (total 50 mm) over the surface area of 0.001734 m^2. The resulting water residence time, defined as elapsed time since a water particle entered the soil core ((Danesh-Yazdi et al., 2016), was approximately 1 h. The leachate was filtered through a 0.45 μm pore size syringe-filter and filtrate was stored at −20 °C, until analysis of nitrate ($NO_3^- - N$), ammonium ($NH_4^+ - N$), dissolved organic N (DON),