Science of the Total Environment 584–585 (2017) 339–347

Contents lists available at ScienceDirect

Science of the Total Environment

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

Impacts of converting low-intensity pastureland to high-intensity bioenergy cropland on the water quality of tropical streams in Brazil

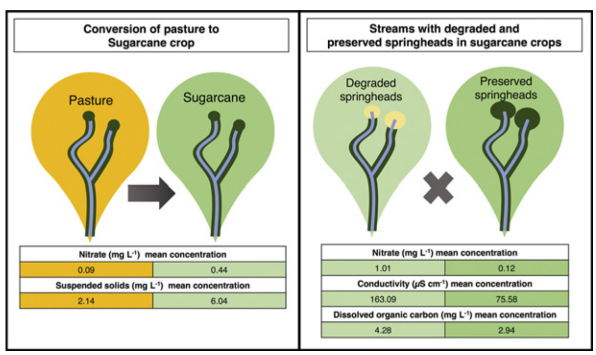
Ricardo Hideo Taniwaki [a,*], Carla Cristina Cassiano [a], Solange Filoso [b], Silvio Frosini de Barros Ferraz [a], Plínio Barbosa de Camargo [c], Luiz Antônio Martinelli [c]

[a] Forest Hydrology Laboratory, Department of Forest Sciences, Luiz de Queiroz College of Agriculture, University of São Paulo. Av. Pádua Dias 11, CEP 13418-900 Piracicaba, SP, Brazil
[b] Chesapeake Biological Laboratory, University of Maryland Center for Environmental Science, P.O. Box 38, 20688 Solomons, MD, USA
[c] Isotopic Ecology Laboratory, Centro de Energia Nuclear na Agricultura, University of São Paulo. Av. Centenário 303, CEP 13416-000 Piracicaba, SP, Brazil

HIGHLIGHTS

- We investigated the effect of landscape use and structure on headwater streams.
- Pastureland to sugarcane field conversion reduced the water quality.
- Preservation of headwater forest in sugarcane fields helped mitigate these negative effects on the water quality.
- Native forests should be preserved in the headwaters and in riparian zones of watersheds with sugarcane.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 29 August 2016
Received in revised form 28 November 2016
Accepted 22 December 2016
Available online 28 December 2016

Editor: D. Barcelo

Keywords:
Suspended sediment
Headwaters
Land-use change
Nitrate
Sugarcane

ABSTRACT

In Brazil, the cultivation of bioenergy crops is expanding at an accelerated rate. Most of this expansion has occurred over low-intensity pasture and is considered sustainable because it does not involve deforestation of natural vegetation. However, the impacts on the water quality of headwater streams are poorly understood, especially with regard to the influence of land use patterns in the watershed. In this study, we investigated the effects of land-use conversion on the water quality of streams draining sugarcane fields and examined whether the preservation of forested areas at the top of the headwaters would help mitigate the negative impacts of intensive agriculture. Water samples were collected in two paired catchments in southeastern Brazil, which is one of the largest sugarcane production regions in the world. Our results show significant differences in the water quality of streams predominantly draining the pasture or the sugarcane field. Several parameters commonly used to indicate water quality, such as the concentrations of nitrate and suspended solids, were significantly higher in the sugarcane than in the pasture stream. Differences in water quality between the streams draining predominantly pasture or sugarcane fields were accentuated during the wet season. The preservation of forests surrounding the headwater streams was associated with overall better water quality conditions, such as lower nitrate concentrations and temperature of the stream water. We concluded that forest conservation in the headwater agricultural

Abbreviations: rmANOVA, repeated measures analysis of variance; SC, catchment converted from pasture fields to sugarcane crops; P, catchment predominantly covered with pasture fields; SCRS (sugarcane + riparian buffer + springhead), catchment with preserved headwater forest; SCR (sugarcane + riparian buffer), catchment without preserved headwater forest.

* Corresponding author at: Forest Hydrology Laboratory, Department of Forest Sciences, Luiz de Queiroz College of Agriculture, University of São Paulo, Av. Pádua Dias 11, CEP 13418-900 Piracicaba, SP, Brazil.

E-mail addresses: rht.eco@usp.br (R.H. Taniwaki), cccassiano@usp.br (C.C. Cassiano), filoso@umces.edu (S. Filoso), silvio.ferraz@usp.br (S.F.B. Ferraz), pcamargo@cena.usp.br (P.B. Camargo), martinelli@cena.usp.br (L.A. Martinelli).

http://dx.doi.org/10.1016/j.scitotenv.2016.12.150

catchments is an important factor preventing water quality degradation in tropical streams. Therefore, we strongly recommend the preservation of robust riparian forests in the headwaters of tropical watersheds with intensive agriculture. More studies on the effects of best agricultural practices in bioenergy crops can greatly improve our capacity to prevent the degradation of water quality in the tropical waterways as intensive agriculture continues to expand in this region of the world.

1. Introduction

Water quality degradation has been observed around the world as a result of land-use changes, such as deforestation, afforestation, agriculture intensification, urbanization, and climate change, operating individually or simultaneously (Buendia et al., 2016; Bussi et al., 2016a, 2016b; Rodríguez-Lloveras et al., 2015). Water quality degradation results mainly from increases in nutrient concentrations, water temperature, and sediment loadings transported from the watershed into aquatic ecosystems (Rodríguez-Lloveras et al., 2015; Worrall and Burt, 1999), which negatively affect the ecosystem structure and function (Guecker et al., 2009). Water quality degradation has also serious economic consequences, such as increasing costs with water treatment (Cunha et al., 2016).

In the tropics, agriculture expansion to meet growing food demand and biofuel production is the primary cause of deforestation and land use changes, projected to increase at least 50% by 2050 (DeFries and Rosenzweig, 2010). Expansion of sugarcane has been particularly significant as sugarcane is the predominant feedstock planted in the tropics for biofuel production (Langeveld et al., 2014). Much of this expansion has taken place in Brazil, which has become the second largest ethanol producer in the world, with sugarcane fields covering an area of >10 million ha (Langeveld et al., 2014). However, the impacts on freshwater ecosystems is largely unknown, not only in Brazil but in the Neotropical region in general, which is one of the most biodiverse regions in the world (Dudgeon et al., 2006; Siqueira et al., 2015).

The expansion of sugarcane in Brazil in the past couple of decades has occurred primarily at the expense of pasturelands and annual crops, especially in the southeast region of the country. In less than a decade, between 2000 and 2009, about 1.5 million ha of pastureland in Brazil was converted to sugarcane fields (Filoso et al., 2015). However, because sugarcane replaced mostly degraded pastures, this conversion has been seen as positive or justifiable as it helps the country meet the growing demand for bioenergy production without contributing to deforestation (Alkimim et al., 2015).

Unfortunately, agricultural intensification is usually accompanied by several potential sources of negative impacts to freshwater ecosystems, such as soil displacement and compaction from the use of heavy machinery, and fertilizer and pesticide application (Martinelli and Filoso, 2008). Headwater streams are especially vulnerable to the impacts of intensive agriculture (Cibin et al., 2016; Diaz-Chavez et al., 2011; Taniwaki et al., 2016), yet, they represent the majority of water bodies in individual catchment basins (Benda et al., 2005) and are vital to maintaining the water quality and health of the entire river ecosystems (Alexander et al., 2007).

Protecting riparian buffers and headwater forests, and increasing the ratio of forest to agricultural area in the watershed are measures commonly recommended to minimize the negative impacts of intensive agriculture on the streams (Bussi et al., 2016a, 2016b; Dosskey et al., 2010; Ferreira et al., 2012; Filoso et al., 2015; Johnes and Heathwaite, 1997; Sliva and Willians, 2001). The riparian buffers are known to reduce the negative effects of upland management through nutrient sequestration, sediment filtering, and maintenance of local microclimates (Clinton, 2011). In the humid tropics, such measures should be especially effective at protecting the headwater streams during the wet season, because heavy rainfall is associated with relatively high upland runoff and the transport of soil particles and pollutants to streams (Taniwaki et al., 2016; Wohl et al., 2012; Wohl and Ogden, 2013). However, the position and configuration of forested areas in the landscape are important factors determining their capacity to mitigate the effects of intensive agriculture on waterways (Souza et al., 2013; Fernandes et al., 2014; Ferraz et al., 2014). Presently, information about how and where the riparian buffers can be used to effectively protect the tropical headwater streams from degradation associated with agriculture intensification and biofuel feedstock production is scarce.

In this study, we assess the effects of converting low-intensity pastureland to high-intensity bioenergy crops and the influence of riparian and headwater forest conservation on the water quality of tropical headwater streams draining catchments converted to intensive agriculture fields for biofuel production. The water quality of the headwater streams was assessed using the common chemical indicators of stream health, such as water temperature, dissolved oxygen, conductivity, dissolved organic carbon, nitrate, and suspended solids, using the paired catchment approach.

We predicted the following differences in the water quality of streams draining the catchments with sugarcane versus low-intensity pastureland: (i) Higher water temperature, nutrient and sediment concentrations, and lower oxygen and dissolved organic carbon concentrations in the stream draining the sugarcane fields (ii) more evident impact of land use conversion to high intensity agriculture in the wet season due to excess overland runoff.

In the sugarcane catchments, already converted from low-intensity pastureland to sugarcane fields with and without the protected headwater forests, we predicted (iii) higher water temperature, nutrient and sediment concentrations, and lower oxygen concentrations in the streams without the protected headwater forests, and (iv) the role of the preserved headwater forests at controlling the water quality of streams should be more evident in the wet season.

2. Material and methods

2.1. Study area

We collected water samples from two pairs of catchments located in the Corumbataí River basin of São Paulo, Brazil (centered on 47°40′W, 22° 40′S; Fig. 1). The basin is 1700 km^2 and has historically gone through extensive changes in land use (Ferraz et al., 2014). Sugarcane fields currently cover ~32% of the arable area of the river basin, and sugarcane cultivation is the main economic activity in the region. Pasture and forestry account for about 25% and 20% of the land cover, respectively. The region has a humid subtropical climate, with well-defined wet and dry seasons and with dry winters and wet summers (Cwa, according to the Köppen classification system) (Cetra and Petrere, 2006). The mean winter temperature is 17 °C, whereas the mean summer temperature exceeds 22 °C (Ferreira et al., 2012). The mean annual rainfall is 1700 mm (Ferreira et al., 2012) with 80% of it occurring during the wet season (Mori et al., 2015).

The first pair of catchments (P and SC) was used to evaluate the effect of the conversion of low-intensity pastureland to sugarcane crops on the water quality of the adjacent streams. Both the catchments drain first-order streams and have similar topography, channel configuration, and soil type (Ultisols) (Supplementary material 1). The geological formations in both the catchments are "Corumbataí" (siltstone and mudstone) and "Piramboia" (sandstones, siltstones and shales)