Ecological Engineering 98 (2017) 146–156

Contents lists available at ScienceDirect

Ecological Engineering

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

Soil humic acid and aggregation as restoration indicators of a seasonally flooded riparian forest under buffer zone system

Andrei Kimura[a], Marcio B. Baptista (Professor)[b], Maria Rita Scotti (Professor)[c,*]

[a] Postgraduate Program/Department of Botany, Institute of Biological Science, Federal University of Minas Gerais, Brazil
[b] Department of Hydraulic Engineering and Water Resources, Federal University of Minas Gerais, Brazil
[c] Department of Botany, Institute of Biological Science, Federal University of Minas Gerais, Brazil

ARTICLE INFO

Article history:
Received 12 September 2015
Received in revised form 19 August 2016
Accepted 11 October 2016
Available online 28 October 2016

Keywords:
Aliphatic C
Aromatic/vinyl C ratio
Fulvic acid
Humic substances
Macro-aggregates
Soil porosity

ABSTRACT

A degraded riparian forest that has lost vegetation and has suffered periodic flooding was rehabilitated using native species under buffer zone system which was stratified according to the distance from the river (Zones I, II, III). To restore the soil stabilisation and water flow we compared the soil aggregation, porosity and soil humic substances of the experimental site (ES) with those of a disturbed site (DS) and a preserved site (PS). Six years post-transplantation, soil aggregation and micro-porosity were improved in the ES relative to the DS, but only micro-porosity achieved a pattern similar to that of the PS in Zone III. Differences in soil aggregation between ES and PS were correlated with the negative effect promoted by a high aliphatic-humic acid composition in Zone I and by an undifferentiated distribution of fulvic acid among sites which were attributed to the flooding effect. Similarities among ES and PS were related to aromatic:vinylhumic acid ratio, allowing for the clustering of samples from Zones II and III of both the PS and the ES, via a principal component analysis. Samples from Zones I of ES and PS were separated driven by aliphatic and fulvic acid contributions, while all of the DS samples formed an isolated group under the influence of aliphatic species and macro-porosity. Based on these attributes, the ES is evolving towards the PS, and the rehabilitation process has attained an intermediate phase of restoration. The zones system adopted for riparian forest restoration allowed the use of soil humic substances, aggregates and micro-porosity as indicators of restoration.

1. Introduction

Riparian forests (RF) aretransition zones between aquatic and terrestrial environments (Lowrance et al., 1997) that play a key role as floodplain buffer systems (Naiman and Decamps, 1997). RF vegetation stabilises stream banks; reduces erosion (Naiman and Decamps, 1997); and intercepts surface runoff, wastewater, and subsurface and deeper groundwater flows to buffer the effects of sediments, nutrients and organic carbon (Lowrance et al., 1997; Anbumozhi et al., 2005).

According to the US Natural Resources Conservation Service (NRCS), a riparian buffer system consists of three functional zones and the hyporheic zone established to assure ecosystem services related to drainage and soil stabilization in floodplain areas under anthropic pressure such as agriculture, pasture and industrial activities. In concordance with NRCS, other studies (Welsch, 1991; Lowrance et al., 1997; Sheridan et al., 1999; Schultz et al., 2004) categorised the zones of riparian forest buffer systems (RFBS) as follows: hyporheic zones consisting of the groundwater area in which a bidirectional flux between stream water and groundwater occurs. Zone I, an area of permanent woody vegetation positioned immediately adjacent to the stream bank whose primary function is to stabilise the margins; Zone II, which includes the strip upslope from Zone I consisting of preserved or managed forest and where litter biomass in puts must be prioritised to support buffering functions; and Zone III, representing the last transitional zone of the riparian terrestrial ecosystem, which includes woody and herbaceous species that control surface erosion.

The movement of soil and water/air in soil is controlled by a soil structure formed from an arrangement of solids and void components (Bronik and Lal, 2005) that facilitate soil stabilisation. This function is promoted by trees and their root systems (Gholami and Khaleghi, 2013) and by soil aggregation. The latter is achieved via the humic substances, through the action of biota, clay, ionic

* Correspondence to: Avenida Antonio Carlos, 6627 Pampulha, Cep: 31, 270−901, Belo Horizonte, Minas Gerais, Brasil.
E-mail addresses: gera.researchgroup@gmail.com, mritascottimuzzi@gmail.com (M.R. Scotti).

http://dx.doi.org/10.1016/j.ecoleng.2016.10.054
0925-8574/

bridging and polyvalent cations (Duiker et al., 2003). Thus, microaggregates (<250 μm) are formed and, once combined with other particles, form macro-aggregates (>250 μm) as described by Tisdall and Oades (1982).

Humic substances (HSs) are considered to be formed during the decay of plants rich in lignin (lignin theory) as described by Stevenson (1994) as well as by cutin and suberin whose residues are resistant to biodegradation by microbial action (Tao et al., 1999). More recently, the lignin theory has been confirmed as the primary source of humification, particularly by condensed aromatic molecules often referred as black carbon (DiDonato et al., 2016). HSs have recently been described as small heterogeneous molecules held together mainly by hydrophobic and H bonding forces in supramolecular associations (Piccolo, 2002), as shown in humeomic studies (Nebbioso et al., 2014; Nebbioso and Piccolo, 2012). Humic acids and humin have a higher molecular weight and represent a more condensed fraction of HSs, whereas fulvic acids are characterised by lower molecular weights and are composed of more oxidised substances than humic acids (Hertkorn et al., 2002). Humic substances vary widely in terms of structural composition, and the fraction linked to minerals in aggregates show high proportions of recalcitrant compounds with varied aromatic C:aliphatic and alkyl-C compositions (Golchin et al., 1994). These shifts result in differences in the quality and functions of humic matter in soil aggregation and stabilisation (Baigorri et al., 2009).

Soil aggregation indices particularly macro-aggregation (Gupta and Germida, 2015) can also be affected by environmental impacts such as vegetation loss, long-term cultivation and soil management (Tivet et al., 2013). These factors can limit humic acid aromaticity (Aranda et al., 2011; Tisdall and Oades, 1982) and the transient microbial community, thus favouring soil disaggregation (Gupta and Germida, 2015). Flooding has been highlighted as a relevant environmental impact that modifies soil aggregation (Yoo et al., 2011) affecting soil microbial communities, decomposition processes, humic acid formation and, ultimately, the formation and stabilisation of soil aggregates (Glazebrook and Robertson, 1999) and soil porosity. Therefore, losses of soil aggregation elements such as soil carbon, fulvic and humic acid may be considered as indicators of land management (Tivet et al., 2013) and degradation (Six and Paustian, 2014).

The Velhas River is the primary tributary of the São Francisco River, one of the most important rivers in Brazil. Its riparian forest has been degraded through anthropic hydrologic and geomorphological processes (Kimura and Scotti, 2016). The study site of the present investigation is an eroded riparian area that has experienced annual flooding from the Velhas River and that has suffered an intense destabilisation at the margins as a result of vegetation loss. To improve the physical stabilisation of the margin of a riparian forest fragment, a timber cribbing cross-section and a system of groynes were installed prior to re-vegetation using native species in a buffer zone system.

The aims of this study was to evaluate the effects of the established riparian forest buffer zones on the quantitative and qualitative composition of humic substances and their relationship with soil aggregation and porosity in order to assess the rehabilitation process.

2. Materials and methods

2.1. Study sites

The ES consisted of a riparian site located on the right bank of the Velhas River in the city of Sabará, Minas Gerais State, Brazil. This riparian site belongs to a slaughterhouse (19°50′21.82″S; 43°51′59.65″O). After the loss of the original vegetation of tropical savanna (Rizzini, 1997) due to anthropic clear-cutting, the area was occupied by pioneer and invasive species such as *Brachiaria decumbens* and *Ricinus communis.* The mean annual temperature here ranges from 22 to 23 °C, with dry winters and rainfall during the summer and the total annual rainfall is 1200 mm (Godim Filho et al., 2004). This site has suffered annual floods that have affected slaughterhouse dependencies, and flow rates have increased from 2810 m^3/s to 8000 m^3/s in the region (Godim Filho et al., 2004).

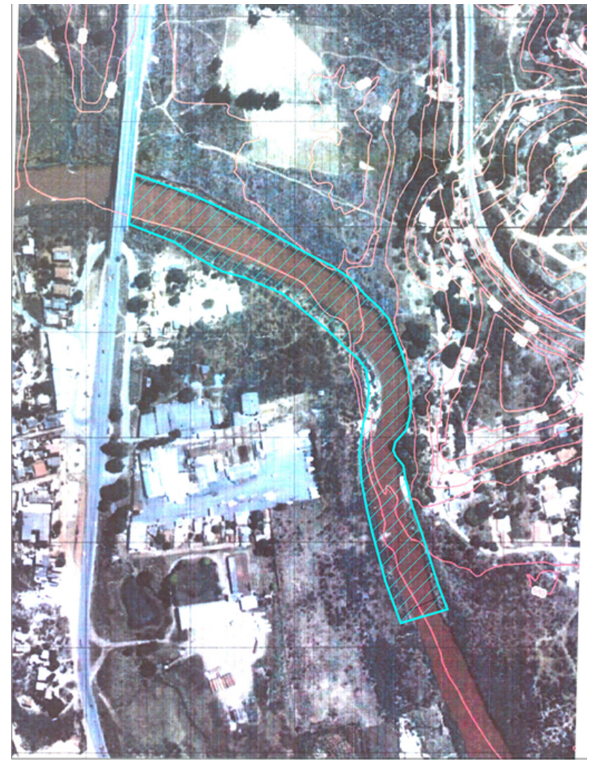

Fig. 1. Definition of the flooded area for different return periods based on hydraulic model, using the HEC-RAS software (River Analysis System).

2.2. Establishment of study sites and experimental design

A riparian forest using native species was established in this area (120 m × 45 m = 5400 m^2) by reconstructing a floodplain river that could perform the natural functions or environmental services of soil stabilisation and water drainage (experimental site). A preserved riparian forest (120 m along the stream × 45 m along the hill slope) was chosen as a positive reference of biological, physical and chemical integrity. This forest was located near the ES (50 m) within an Environmental Protection Park, upstream to ES which is covered primarily by riparian tropical forest (woody savanna). A degraded site (120 m along the stream × 45 m along the hill slope) adjacent to the ES without woody vegetation in which dominant vegetation was pioneer and invasive species (*Brachiaria decumbens* and *Ricinus communis*) was chosen as a negative control. This area showed soil and environmental conditions similar to the ES before transplantation.

In the study area, we performed two topographic and bathymetric analyses to establish and calibrate a hydraulic model using HEC-RASsoftware (Hydrologic Engineering Center's –CEIWR-HEC- and River Analysis System- USA). This model allowed the definition of the flooded area for different return periods (Fig. 1) and the calculation of the associated drag forces (Vieira, 2008) in order to establish the riparian forest area and location.