Soil Biology & Biochemistry 78 (2014) 97–108

Contents lists available at ScienceDirect

Soil Biology & Biochemistry

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

The match between microbial community structure and soil properties is modulated by land use types and sample origin within an integrated agroecosystem

Francy Junio Gonçalves Lisboa [a, *], Guilherme Montandon Chaer [b], Marcelo Ferreira Fernandes [c], Ricardo Luis Louro Berbara [a], Beata Emoke Madari [d]

[a] Soil Science Department, Agronomy Institute, Federal Rural University of Rio de Janeiro, Seropédica, RJ, 23890000, Brazil
[b] Embrapa Agrobiology (Embrapa Agrobiologia), Seropédica, RJ, 23890-000, Brazil
[c] Embrapa Coastal Tablelands (Embrapa Tabuleiros Costeiros), Aracajú, SE, 49025-040, Brazil
[d] Embrapa Rice and Beans (Embrapa Arroz e Feijão), Santo Antônio de Goiás, GO, 75375-000, Brazil

ARTICLE INFO

Article history:
Received 26 May 2014
Received in revised form
26 July 2014
Accepted 27 July 2014
Available online 10 August 2014

Keywords:
Management
Tree-based systems
Agroecosystems
Microbial community
Procrustean association metric

ABSTRACT

It is of global concern to adopt measures to mitigate land degradation caused by agricultural production systems. One of the strategies proposed is to replace degraded pastures with agrosilvopastoral systems which integrate three different land-use types: crop production, livestock pasture and forestry plantation (denoted iCLF). However, little is known about the differences between iCLF and other land use types in terms of soil microbial community structure. Distance matrices based on individual soil chemical properties and individual soil microbial variables were correlated by Procrustes analysis and these relationships yielded vectors of residuals depicting these correlations (matches). These vectors were used as univariate response variables in an ANOVA framework in order to investigate how the match sizes (the strength of correlation/covariance) between individual soil chemical properties and individual soil microbial variables vary across land use types (levels: iCLF; degraded pasture; improved pasture; and a native cerrado fragment) and also across sample origin within iCLF (levels: soil samples under more influence of the exotic tree forest stand; soil samples under influence of the pasture; samples within the transition between the forest stand and the pasture). We were able to obtain insights into the fact that the land use distinction can be driven by more than just individual soil chemical and microbial variables. The integration of crop, livestock and forestry promoted a dominance of fungi in this low fertility and low pH environment. P availability and the composite variable exchangeable base cations (Ca^{+2}, Mg^{+2}, K^{+}) were the soil properties whose strengths of correlation (match sizes) with individual microbial variables were the most affected by land use type and sampling origin within iCLF. While the strength of the correlation between soil microbial structure variables and P availability was typically land use type dependent, the response of the microbial structure to exchangeable base cations was mainly affected by the sample origin within iCLF. Finally our results point towards the conclusion that increases in the heterogeneity of vegetation within integrated crop, pasture and forestry systems are an important driver of microbial community response to environmental changes, and may be one means by which to increase the sustainability of tropical agroecosystems.

1. Introduction

Global concern with farmland degradation, usually associated with soil carbon loss, has led numerous countries to seek management strategies aimed at the restoration and sustainable use of such areas. In Brazil, special attention is being paid to integrated crop-livestock-forest systems (iCLFs) for replacing pastures in different stages of degradation. Approximately 12% of the Earth's land surface is covered by agricultural crops, 33% is intended for livestock, and 15% supports exotic forest species (Giraldo et al., 2011). Pastures accumulate large quantities of carbon in the topsoil layers due to the profusion of fine roots from grasses but produce relatively less recalcitrant substrates compared to forest systems. This favors organic matter mineralization by stimulating a

* Corresponding author. Tel./fax: +55 21 26828045.
E-mail address: agrolisboa@gmail.com (F.J.G. Lisboa).

http://dx.doi.org/10.1016/j.soilbio.2014.07.017

microbial structure with a higher activity (Bardgett and McAlister, 1999) consequently inducing higher soil carbon losses (Millard and Singh, 2009). A recent study showed that vegetation homogenization generated by converting natural forests into pastures may be accompanied by homogenization of the microbial communities (Rodrigues et al., 2013), most likely due to a reduced diversity of good quality substrates per soil volume (Lamb et al., 2010). In contrast, the introduction of tree species may promote microbial diversity when converting pastures into exotic species forests (Carson et al., 2010).

It is believed that changes in microbial community structure generated by modified land management and land use type can be related to the soil switching from carbon source to carbon sink or vice versa. Additionally, it is suggested that land use types considered to be more conservative regarding organic matter mineralization tend to exhibit a microbial structure with lower activity (Bardgett and McAlister, 1999). Within this formulation, iCLF systems, which combine crop production, managed pasture and forest species, are designed to exhibit a microbial structure distinct from that of degraded pastures via plant physiological heterogenization of the landscape. However, soil microbial community structure is rarely investigated in agrosilvopastoral systems such as iCLF systems, especially in the tropics (Lacombe et al., 2009; Vallejo et al., 2012). Thus, we do not have a large body of evidence that iCLF systems may be more carbon conservative.

Changes that occur in vegetation composition due to land use type conversion are responsible for most of the variation that occurs in chemical and physical soil properties. In turn, these changes tend to correlate with variation in the microbial community, linking the changes above and below the soil surface (Mitchell et al., 2010; Lisboa et al., 2012). However, the extent to which this link between soil chemical variables and the phenotypic structure of the microbial community is partitioned among different land use types, as well as how the human-induced plant heterogeneity, introduced by the forest component in the integrated crop-livestock-forest (iCLF), is able to differentiate it from the other land use types, remain unaddressed questions.

In this study, we started with the hypothesis that introducing iCLF as a replacement for degraded pastures leads to a change in the response of the phenotypic composition of the soil microbial community to individual soil chemical variables. We accessed the individual responses of soil and microbial phenotypic variables to land use type in three different scenarios: 1) considering all samples in the iCLF, 2) considering only samples from the centre of the pasture component of the iCLF; 3) considering only samples from the forest stand within the iCLF.

For the main point in this study, i.e. how the matches/effects of individual soil chemical variables on the individual microbial variables are partitioned by land use type and sampling origin within the iCLF, we used features from Procrustes analysis (Gower, 1971). Similar to the more traditional Mantel test, Procrustes analysis is a correlative multivariate approach. However the correlation in Procrustes analysis is reached through rotation and translation, seeking for the "best" fit that depicts the minimal residual difference between homologous coordinates of two or more matrices under analysis (Peres-Neto and Jackson, 2001; Lisboa et al., 2014). These homologous coordinates are nothing but the rows (sites, samples) of the matrices under analysis so that low residuals stand for strong matches/effects whereas high residual differences mean weak matches/effects. Procrustes has the feature of providing the matches among all homologous coordinates of matrices under analysis in a vectored form sometimes called the Procrustean association metric (Lisboa et al., 2014). Thus this vector can be retained for using in downstream statistical approaches in order to investigate the consistencies in the size of the matches across different environmental predictors. In the present study we investigated the consistency in size matches from the Procrustean association metric between distance matrices based on individual soil chemical variables and soil microbial variables in an ANOVA framework having the land use type as a factor (first ANOVA) or sample origin within the iCLF as a factor (second ANOVA).

2. Materials and methods

2.1. Study area

The study was conducted in one of the 203 technology reference units in the iCFL (http://www.cnpgl.embrapa.br/nova/silpf) of the Brazilian Agricultural Research Corporation (Empresa Brasileira de Pesquisa Agropecuária - Embrapa) on the Boa Vereda farm located in the municipality of Cachoeira Dourada, Goiás State, Brazil (Fig. 1A and B). The study site is located at 18°27′43.19″S, 49°35′58.53″W at an altitude of 484 m above sea level, on a clay (603 g kg^{-1}) Rhodic Ferralsol (Latossolo Vermelho acriférrico típico (Brazilian Soil Classification System) or Anionic Acrustox (Soil Taxonomy)) with slopes between 0 and 15% and a mean annual rainfall of 1350 mm (Brasil, 1983). Four land-use types were assessed in this study (Fig. S1): 1) an iCLF system; 2) improved pasture with remnants of dry forest natural vegetation (native trees); 3) degraded pasture; and 4) a native cerrado fragment (savannah-like) exhibiting 'cerrado denso' (dense tree savannah) vegetation.

2.2. History of land use types

Originally, all of the sites studied were covered with 'cerrado' vegetation, within which they represented forest formations of dry forest, 'cerradão' (woodland), and 'cerrado denso'. All of the areas, except the original forest, had been deforested for more than 30 years and were maintained as pasture until recently.

2.2.1. iCLF

In 2009, the iCLF system was implemented with three rows of eucalyptus trees per stand, using 476 trees per hectare (ha), in a total area of 14.7 ha with the following management sequence: in August, the soil was plowed with a disc harrow at a cutting depth of 25 cm, and lime was incorporated into the soil. Between October and November, the soil was prepared for planting soybean (*Glycine max* L. variety BRSGO 8360) and eucalyptus (*Eucalyptus urograndis*) with a leveling disc harrow. In October 2010, the soil was prepared again for planting corn (*Zea mays* L.) intercropped with brachiaria grass (*Urochloa brizantha*). After harvesting the corn, the soil was not mechanically turned anymore, and the brachiaria grass developed into pasture between the eucalyptus rows. The soybean crop received 300 kg ha^{-1} 04-30-10 (NPK) + Zn formula fertilizer, the corn received 300 kg ha^{-1} 08-30-10 + Zn and the eucalyptus crop received 150 and 10 g $plant^{-1}$ of 08-30-10 + Zn and boric acid, respectively. As maintenance fertilizer, the eucalyptus received 200 kg ha^{-1} of simple superphosphate broadcasted and 15 g ha^{-1} boric acid, and the pasture between the eucalyptus rows received 100 kg urea ha^{-1} and 100 kg ha^{-1} monoammonium phosphate annually.

2.2.2. Improved pasture

Before the pasture was restored, it was in a situation of abandonment. In 2008, the site was restored, starting with a disc harrow. Then, lime was applied and incorporated into the soil with a leveling harrow, followed by planting *Brachiaria* grass that continues to grow on the site.