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Relating the visual soil structure status and the abundance of soil engineering invertebrates across land use change

André L.C. Franco[a,*], Maurício R. Cherubin[a], Carlos E.P. Cerri[a], Rachel M.L. Guimarães[b], Carlos C. Cerri[c]

[a] University of São Paulo, "Luiz de Queiroz" College of Agriculture, Department of Soil Science, 11 Avenida Pádua Dias, Piracicaba, SP 13418-900, Brazil
[b] Federal University of Technology-Paraná, Department of Agronomy, Via do Conhecimento, km 1, Pato Branco, PR 85503-390, Brazil
[c] University of São Paulo, Center for Nuclear Energy in Agriculture, 303 Avenida Centenário, Piracicaba, SP 13400-970, Brazil

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ABSTRACT

Visual Evaluation of Soil Structure (VESS) method assesses the status of soil structural quality through the examination of soil physical characteristics and biological features. Consistent relationships between VESS scores and quantitative soil physical properties have been demonstrated. However, how VESS scores correlate with quantitative soil biological properties remains unknown. This study assessed relationships between soil structural quality responses to land use change (LUC) and alterations in soil macrofauna in arable tropical soils. We simultaneously measured soil structural quality through VESS method and the abundance and community structure of macrofauna in chronosequences of land uses comprising pasture and sugarcane crop along a 1000-km-long transect through two major tropical biomes in Brazil. Correlation matrix and principal component analysis (PCA) were performed to elucidate correlations between the measured variables. Average VESS scores were 2.5 and 3.0 for pasture to sugarcane, respectively, showing a deterioration of soil structural quality following LUC. Soil macrofauna abundance and richness, as well as the abundance of individual dominant macrofauna groups, consistently decreased from pasture to sugarcane. PCA explained 56.5% of the variance, with pasture soils mostly associated with macrofauna variables, and sugarcane soils grouped near the VESS score. Correlation matrix and PCA showed positive correlation between the deterioration of soil structure after LUC and reductions in the size of macrofaunal community, especially termites ($r_{spearman} = 0.36$; $P = 0.012$). These results indicate that VESS scores correlate well with the abundance and richness of major soil engineers.

1. Introduction

Soil structure is defined as the size and arrangement of particles and pores in soil (Hartge and Stewart, 1995), and it regulates a large number of ecological functions including water dynamic in soil (Connolly, 1998), gas exchanges (Plaza-Bonilla et al., 2014), soil organic matter and nutrient dynamics (Fonte et al., 2014; Tisdall and Oades, 1982), and the susceptibility of soil to erosion (Barthes and Roose, 2002). The visual evaluation of soil structure (VESS) method has been successful applied to evaluate soil structure and soil quality under different land use and soil management strategies (Abdollahi et al., 2015; Guimarães et al., 2013; Moncada et al., 2014a). The scoring system of VESS reflects a comprehensive view of soil quality status that stems from the examination of soil physical characteristics (color, porosity, and aggregation), as well as biological features (roots, and traces of soil fauna activity) (Guimarães et al., 2011). The relationships between VESS score and quantitative soil physical properties such as soil resistance to penetration, bulk density, and the least limiting water range have been shown to be consistent (Askari and Holden, 2014; Guimarães et al., 2013; Moncada et al., 2014b). However, there is a lack of knowledge regarding how the VESS scores correlate with quantitative measurements of soil biology conditions.

The incorporation of fresh organic matter in the soil by some groups of soil fauna, such as earthworms, termites, ants, and coleopteran insects, has major consequences for soil structure as it controls soil porosity and soil aggregate formation and stabilization (Tisdall and Oades, 1982). Some of these invertebrates also influence soil structure by coating their galleries that run through the soil profile (Bottinelli et al., 2015). The role that soil fauna plays in influencing soil structure dynamics is conceptually recognized

* Corresponding author. Present address: Department of Biology, Colorado State University, Fort Collins, CO 80523, USA.
E-mail address: andre.franco@colostate.edu (A.L.C. Franco).

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in VESS, where soil fauna provides both a diagnostic tool (e.g., a low number of distinct worm holes in non-porous aggregates indicates a poor soil structural quality) and a recommended management for soil quality recovery in degraded areas (improvement by management strategies that facilitate biological activity is required if the layer is scored a 3 and most aggregates are angular and sharp-edged with no visible porosity) (Guimarães et al., 2011).

This research tested the hypothesis that soil structural quality, as measured by VESS score, is related to the size and composition of the soil (macro)faunal community in tropical soil. Our objective was to assess the responses of soil structural quality to land use change (LUC) and its relationship with alterations in soil macrofauna in tropical arable soils.

2. Material and methods

The study was conducted at sites representative of two major tropical Brazil's biomes, Cerrado and Atlantic Forest. Three study sites were identified to represent the northern, central, and southern parts of the region where sugarcane expansion is occurring at the expense of pastures. These sites were chosen along a transect of approximately 1000 km across this region. For each study site we identified a chronosequence of land use for pasture and sugarcane crop, and to minimize the effects of climatic, topographic and edaphic variations, the two land uses were always located in adjacent areas within the sites. Site coordinates and soil characteristics can be found in Table 1. A complete soil chemical characterization as well as detailed information about the land use and soil management history of the study sites is provided by Cherubin et al. (2015). In brief, pasture areas differed from each other in the stocking rate: pasture at Lat_17S supports 1.5 animal unit (AU) ha^{-1}; pasture at Lat_21S supports around 2 AU ha^{-1}; and pasture at Lat_23S supports around 1 AU ha^{-1} through the year. The sugarcane area was established over part of the pasture area in 2009 at Lat_17S, in 2010 at Lat_21S, and in 1990 at Lat_23S.

The field sampling for soil macrofauna and VESS was conducted in the rainy season. High soil fauna richness and reduced variation of abundance were expected during this season, which is more adequate for the assessment of soil fauna (Neto et al., 2012). All samples from a single site were taken on the same day. Sampling points were positioned in representative locations within each land use sampled. Ant or termite nests, burrows of wild animals, and big trees were avoided in native vegetation areas, while preferential cattle trampling paths were avoided in pasture areas. Except at Lat_17S where the soil had been recently tilled for sugarcane replanting, all sampling points in sugarcane fields were located within the interrow position, which is homogeneously tracked during harvest operations. At each land use soil samples were extracted from four sampling points spaced 50 m apart. Two types of undisturbed soil blocks were collected at each sampling point: (i) soil blocks of 25 × 25 cm to 10 cm depth were collected from the 0–10 cm and 10–20 cm soil layers for macrofauna extraction; and (ii) a soil block of 20 × 10 to 25 cm depth was sampled for VESS. Macrofauna samples were sorted according to the standard Tropical Soil Biology and Fertility Institute (TSBF) soil monolith method (Anderson and Ingram, 1993; Moreira et al., 2008). The animals were carefully hand-sorted from the soil blocks in a large tray, immediately after the sampling procedure. Organisms from the litter were added with the 0–10 cm soil macrofauna. The earthworms were preserved in 92.8% ethanol and all the others individuals in 70% ethanol for subsequent laboratory identification and counting. The invertebrates were sorted into the taxonomic groups: Aranae, Blattodea, Chilopoda, Coleoptera, Dermaptera, Diplopoda, Diptera, Formicidae, other Hymenoptera, Gastropoda, Hemiptera, Isopoda, Isoptera, Oligochaeta, and Scorpiones. The VESS assessment and scores were performed as described by Guimarães et al. (2011). The soil evaluation included manual breakdown of soil aggregates along the natural fracture lines on a plastic tray, identification of layers of contrasting structure, measurement of layer depth and assignment of a score by comparing the structure of the sample with the VESS chart, which contains descriptions and pictures of each proposed soil structure quality (Guimarães et al., 2011). The scores range from 1 (good structure) to 5 (poor soil structure). A score was assigned for distinct layers identified according to the standard chart description, and then a weighted average of the score was calculated for the top (0–10 cm) and bottom (10–20 cm) soil layers.

An independent-samples *t*-test was conducted for both soil layers and average 0–20 cm to compare soil properties under pasture and sugarcane using a global average of the results found at the three locations. Significance level was set at $P \leq 0.05$. Multivariate analysis was applied in order to assess the correlations among soil macrofauna and VESS scores. A Principal Component Analysis (PCA) was performed to visualize the correlations among the total abundance, richness, and the abundance of the dominant macrofauna groups (Coleoptera, Formicidae, Isoptera, and Oligochaeta) and VESS scores. PCA was conducted using the software R, version 3.2.2 (R Core Team, 2014). Correlations between soil macrofauna variables (total abundance, taxa richness, and abundance of Coleoptera, Formicidae, Isoptera, and Oligochaeta) and VESS scores were also tested based on Spearman's correlation coefficients.

3. Results and discussion

Fig. 1 shows the distribution of the sampling points, which are shaped according to the land use, with soil variables as explanatory

Table 1
Coordinates, soil classification according to Soil Survey Staff (2014), VESS scores and soil macrofauna variables (total abundance (individual m^{-2}) and richness (number of groups), and the abundance of major groups) for the study sites. Standard error of the mean is presented in parenthesis, $n = 4$.

Site	Latitude	Longitude	Land use	Soil type	Soil layer	VESS score	Abundance	Richness	Oligochaeta	Isoptera	Formicidae	Coleoptera
Lat_17S	17°56′S	51°38′W	Pasture	Typic	0–10	1.46 (0.2)	776 (511.9)	2 (0.4)	4 (4)	744 (497.1)	20 (15.1)	4 (4)
				Hapludox	10–20	2.38 (0.1)	492 (486.7)	0.75 (0.5)	0 (0)	20 (15.1)	0 (0)	472 (472)
			Sugarcane	Anionic	0–10	1.25 (0.3)	24 (8)	1.5 (0.5)	4 (4)	0 (0)	0 (0)	4 (4)
				Acrudox	10–20	3.25 (0.4)	8 (4.6)	0.5 (0.3)	0 (0)	0 (0)	0 (0)	0 (0)
Lat_21S	21°14′S	50°47′W	Pasture	Typic	0–10	1.75 (0.2)	388 (181.7)	3.5 (0.3)	72 (33.6)	156 (150.7)	104 (74)	36 (7.7)
				Kandiudult	10–20	3.75 (0.2)	216 (143.9)	1.75 (1)	140 (94.5)	0 (0)	12 (7.7)	60 (41.5)
			Sugarcane	Typic	0–10	3.2 (0.3)	136 (51.6)	2.5 (0.5)	28 (7.7)	0 (0)	4 (4)	4 (4)
				Hapludalf	10–20	4 (0)	8 (4.6)	0.5 (0.3)	8 (4.6)	0 (0)	0 (0)	0 (0)
Lat_23S	23°05′S	49°37′W	Pasture	Rhodic	0–10	2.03 (0.2)	144 (64.3)	2 (0.9)	36 (36)	64 (41.8)	16 (11.3)	4 (4)
				Kandiudox	10–20	3.85 (0.1)	128 (101.8)	2 (0.8)	20 (7.7)	84 (84)	0 (0)	4 (4)
			Sugarcane	Rhodic	0–10	2.91 (0.4)	64 (27.7)	1.75 (0.5)	4 (4)	0 (0)	16 (11.3)	32 (22.6)
				Hapludox	10–20	3.45 (0.2)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)