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Research paper

Litter and soil-related variation in functional group abundances in cacao agroforests using structural equation modeling

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ABSTRACT

The aim of this study was to apply the method of structural equation modeling using latent variables (constructs) with multi-indicators to test hypothesized interaction models among functional groups of fauna and attributes of litter-soil system in cacao agroforests in the south of Bahia, Brazil. The hypothesized structural model was composed of four constructs: the litter-attributes, litter-fauna, soil-attributes, and soil-fauna. The models tested were able to distinguish between the direct and indirect relationships of the faunal groups and attributes of litter-soil system. The results have shown that the interconnection theory between fauna and attributes of litter-soil system should be presented in more than one structural equation model. The models built from the re-specifications showed a strong theoretical base and data fitted, well representing the fauna as a latent variable (construct) theory within the litter-soil system of cacao agroforests. The overall fit of the hypothesized models highlighted the theoretical plausibility of complex interconnection between soil and litter fauna. Both are influenced by the attributes of their niches. Litter-attributes construct composed only by the indicators lignin, cellulose and polyphenols showed a recalcitrant predominant nature. This low litter nutritional quality would negatively affect the faunal groups therein. The negative relation between litter-attributes and soil-attributes suggest that low-quality litter contributed little to the improvement of soil fertility, particularly related to the level of acidity. The negative relationship between soil-attributes and soil-fauna shows that highly acid and low-fertility soils would promote some restriction on the activity of soil fauna groups. The structural equation modeling with latent variables proved to be a suitable tool for the understanding of the complexity of the relationships between faunal groups within the tested litter-soil system, indicating how the changes in a latent composition would affect other latents. It important to mention that when the approach is about organisms in the litter-soil system, caution is advised when trying, in a mechanistic way, to determine the factors influencing the interconnection of these organisms with their niches, due to the inherent heterogeneity of both litter and soil.

1. Introduction

Agroforestry systems (AFSs) are land use systems of great similarity to natural forests because of the large residue deposition amounts from plant shoot and root, as well as high plant species diversity and constant nutrient cycling. The AFSs are taken as a sustainable alternative for soil use, since they bring a series of environmental benefits such as plant and soil organisms' diversity conservation, carbon sequestration, erosion control and increasing soil fertility (Jose, 2009; Fontes et al., 2014; Monroe et al., 2016).

Cacao agroforestry systems in southern Bahia state (Brazil) have been mentioned as a green and economically feasible farming alternative with concurrent preservation of Atlantic Forest remnants. As cacao is a shade-tolerant plant, two typical cacao production systems are used in south of Bahia Brazil: (1) traditional cultivation system, wherein the cacao plantations are implanted under natural forest, and herbaceous, shrub and individuals of the upper canopy are eliminated to provide increased light input, resulting in extensive agroforestry called 'cabrucas' (Fontes et al., 2014; Monroe et al., 2016); (2) cacao plantations are established in areas where all native forest has been removed and replaced by a single forest species and cacao plants are shaded with banana and other crops such as cassava and maize as provisional shade until the forest species could provide enough shade. Among the forest species used as sunshade, we may cite *Erythrina glauca*, *Gliricidia sepium* and *Hevea brasiliensis* (Lobão et al., 2012; Marques et al., 2012; Müller and Gama-Rodrigues, 2012).

Plant species diversification, continuous plant residue deposition and non-tillage soil of cacao AFSs provide a favorable environment for a

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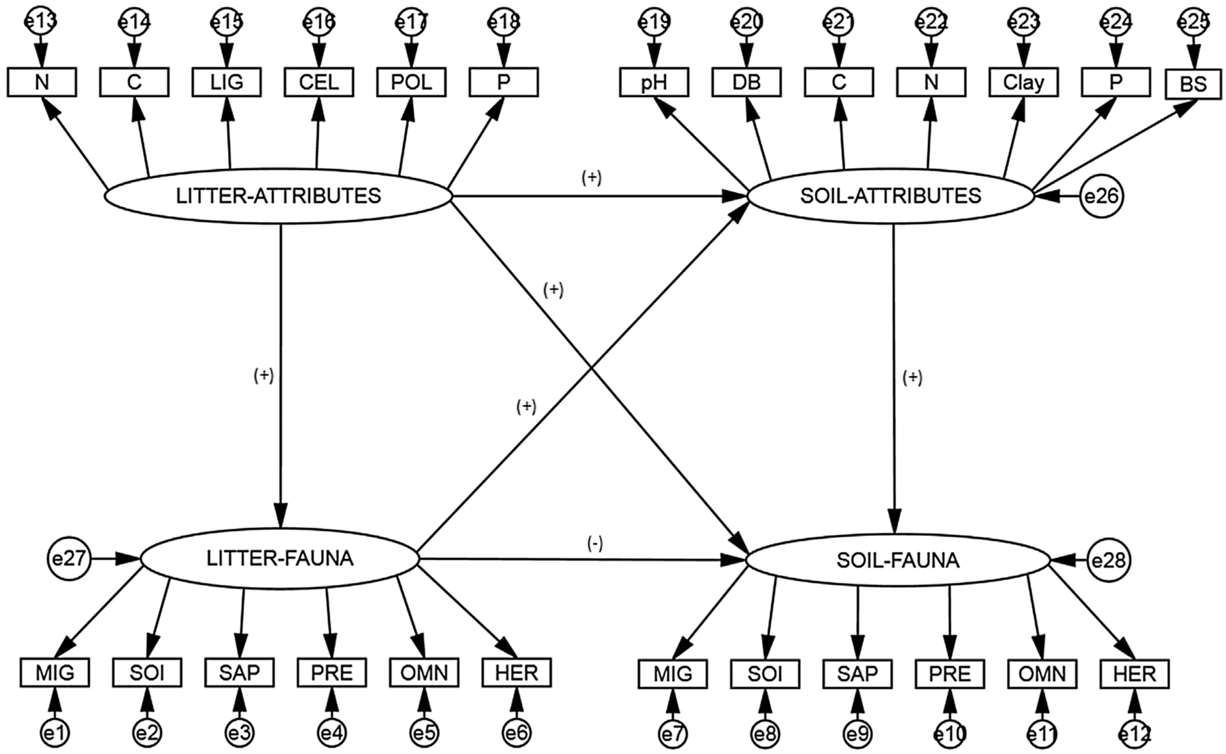

Fig. 1. Model A, the hypothesized structural model for the relationships between invertebrate communities, litter and soil attributes in cacao agroforestry systems. MIG = Microbial Grazers, SOI = Social Insects, SAP = Saprophagous, PRE = Predators, OMN = Omnivores, HER = Herbivores, N = Nitrogen, C = Carbon, LIG = Lignin, CEL = Cellulose, POL = Polyphenols, P = Phosphorus, BD = Bulk Density and BS = Sum of bases.

large soil organism's diversity (Laossi et al., 2008; Moço et al., 2009, 2010) that comprises invertebrates and microflora. According to the relationship between invertebrates and microflora three major groups of invertebrates may be defined. The microfauna comprise invertebrates of less than 0.2 mm, on average, and mainly include Protozoa and Nematodes, predators of bacteria and fungi, and their predators, that live in water filled soil pore space. Mesofauna (invertebrates 0.2–2 mm in size) and macrofauna, large arthropods which normally ingest purely organic material and develop mutualistic interactions in their fecal pellets. Earthworms, termites and, to a lesser extent, ants, are 'ecosystem engineers' that create diverse organic-mineral structures and interact with micro-organisms through an internal rumen type of digestion (Lavelle, 1997; Coleman, 2008).

The litter-soil system is habitat to a wide variety of microorganisms and invertebrates with different sizes and feeding activity. These organisms' communities interact with each other and perform several functions, ranging from fragmentation and decomposition to plant residue mineralization, establishing a structural and functional food web (Parkinson, 1988; Coleman, 2008; Yang and Chen, 2009). Soil and litter attributes have hitherto provided the fundamental context in which such functions operate, and have clear utility in assessing ecological status as key regulators of colonization, survival and activity of soil organisms (Ettema and Wardle, 2002). However, a mechanistic understanding of the relationships between soil organisms and function, whether in relation to the soil as an ecosystem in itself or as part of a larger ecosystem, are undeniably complex and remain elusive (Ritz et al., 2009).

This current study derived from Moço et al. (2010) which aimed to investigate through the path analysis, the direct and indirect effect of soil and litter attributes for each functional groups of fauna. The authors observed that both litter as soil attributes affected differently just some faunal groups and a question remain unclear: How to assess the interdependence between all the functional groups of fauna and attributes of litter-soil system?

Understanding environmental features closely related to soil organisms diversity is extremely important because fauna plays an important role in soil functioning as organic matter decomposer and nutrient-cycling agent. As a result, the challenge in soil ecology is developing multivariate hypotheses to describe not only interrelations between litter and soil attributes or between litter and soil fauna, but also the direct and indirect existing relations between attributes and fauna in the litter-soil system, in a complex interconnection between edaphic environment and organisms similar to Jing et al. (2015), Shao et al. (2015), Bardgett and van der Putten. (2014), Eisenhauer et al. (2013, 2015), García-Palacios et al. (2013), Zhang et al. (2013) in grassland, forest ecosystem and tillage system.

In recent years, structural equation modeling (SEM) has frequently been used to investigate complex networks of relationships in soil ecology (Shao et al., 2015). This method can be used to not only test multivariate hypotheses, but also help to improve them (Gama-Rodrigues et al., 2014; Grace et al., 2014; Eisenhauer et al., 2015). Basically, path models (for observed variables) are mostly used to study the diversity and complexity of the interactions between soil organisms and their interactions with the environment (Scherber et al., 2010; Eisenhauer et al., 2012; Shao et al., 2015; Jing et al., 2015; Allan et al., 2015). Moreover, one of the main features of SEM technique is to include latent variables (non-measured − construct) along with those measured in hypothesized models (Grace and Bollen, 2006). As the latent variables are conceptual variables, they can be used to represent potential underlying causes. This would enhance understanding of the ecological soil system under study.

One of the reasons to use SEM with latent variables is to approach measurement errors, once the observed variable models (path models) assume no measure errors. Furthermore, the error (or error variance) or covariation among error variances indicates the level of latent influence of other external processes onto the model (Grace and Bollen, 2006; Hair et al., 2009).

The structural models fitted with latent variables allow to reduce