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Decomposition of eucalypt harvest residues as affected by management practices, climate and soil properties across southeastern Brazil

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ABSTRACT

Across southeastern Brazil, eucalypt plantations have been established in areas with predominantly low-fertility soils, in which nutrient cycling is critical for forest sustainability. However, despite continuous research on harvest residues (HR) over the last 30 years or more, the extent by which its decomposition rate is affected by management practices, climate conditions and soil properties is not well understood. We evaluated the decomposition of HR in 10 sites under eucalypt plantations within the Mata Atlântica and the Cerrado (savanna-like) biomes, which account for more than 60% of the area under eucalypt plantations in Brazil. In each site, we assessed the decomposition of HR as affected by three major management practices, namely bark removal or its maintenance, HR left on the soil surface or mixed into the topsoil, and N fertilization at 0 or 200 kg ha^{-1}, in a complete factorial scheme, using 4 replicates per treatment. The remaining mass of HR was assessed at 0, 3, 6, 12 and 36 months after the installation of the experiments, yielding a total of 320 samples. HR decomposed 22% faster when it was mixed into the topsoil or when the bark was included, but it was minimally affected by N fertilization. While increasing precipitation, temperature, soil pH, exchangeable Ca and Mg, and sand content led to faster decomposition rates, the opposite occurred with increasing exchangeable Al and clay content. The mean annual precipitation and soil pH combined by multiple linear regressions explained approximately 70% of the variability in the decomposition of HR across the sites. Interestingly, the decomposition rate was inversely correlated to the soil carbon content in our study. Bark maintenance in the fields under eucalypt plantations reduces off-site nutrient exportation and contributes to an increase in the decomposition rate almost by the same extent as by incorporating HR into the topsoil. Additionally, environmental conditions and soil properties also exert strong influence over the decomposition of HR and should be considered for managing nutrient cycling and fertilization programs. This is particularly important for the sustainability of eucalypt plantations established in low-fertility soils across tropical regions.

1. Introduction

In tropical regions, eucalypt plantations are usually established on acidic soils, which fertility is highly dependent upon nutrient cycling through plant litter and the decomposition of harvest residues (HR). In these plantations, HR are also a potential source of soil organic carbon (SOC) and protect the soil surface against erosion after harvesting (Mendham et al., 2003, 2014; Fernández et al., 2004). As a result, the decomposition rate of HR could affect forest sustainability, particularly for fast-growing plantations managed in short and successive rotations (Nambiar, 1996).

Generally, the main drivers of the decomposition rate of plant litter in terrestrial ecosystems are climate, particularly temperature and precipitation, the chemical composition of the plant litter itself, the activity of the microbial biomass, soil fauna, and also the nutrient availability in the soils and the pH (Couteaux et al., 1995; Aerts, 1997; Austin and Vitousek, 2000; Powers et al., 2009; Waring, 2012). Moreover, despite the importance of texture for water retention and gas exchange between the soil and the atmosphere (Scott et al., 1996), its influence over HR is not well understood. With specific regard to forest plantations, management practices such as the incorporation or maintenance of HR on the soil surface also have a strong influence on its decomposition

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(Jones et al., 1999). However, the relative importance of climate and management practices over the decomposition of HR is not well known.

Currently, eucalypt plantations in Brazil yield HR amounts as high as 30 Mg ha^{-1} dry matter (DM) at harvesting (Gatto et al., 2010), including approximately 10 Mg ha^{-1} DM of bark, if only the pulpwood is harvested (Santana et al., 2008). Despite bark maintenance in the fields favoring eucalypt growth in subsequent rotations (Gonçalves and Barros, 1999; Gonçalves et al., 2008, 2013; Santana et al., 2008; Laclau et al., 2010), its impact over the decomposition of HR is not well understood. This is important because irrespective of bark maintenance, all the components of eucalypt HR possess a relatively high C:N ratio. For example, eucalypt leaves present a C:N ratio of 30:1, which is approximately 10 units higher than that for *Acacia mangium* (Koutika et al., 2014). On the other hand, eucalypt leaves have a C:N ratio significantly lower than twigs, branches and bark, all of which present C:N ratios higher than 100:1 (Jones et al., 1999; Versini et al., 2014). In addition, eucalypt HR also have a high concentration of aromatic compounds, which could lead to substantial N immobilization (Corbeels et al., 2003) and temporarily reduce N availability in the soil for the plants in a subsequent rotation (Madeira et al., 2010). Presumably, high N availability in the soil would favor the decomposition of plant litter by stimulating microbial activity (Prescott, 2010). This implies that when the microbial community is limited by N availability within the decaying plant litter, the decomposition rate slows down (Forrester et al., 2013). Therefore, given the biochemical characteristics of eucalypt HR, we expected its decomposition rate to be increased by N fertilization.

In Brazil, minimum cultivation has been applied in more than 80% of the areas where eucalypt is grown (Gonçalves et al., 2013). It follows that minimum cultivation slows down HR decomposition because these materials are left on the soil surface (Gonçalves et al., 2004). Such a slow decomposition rate would be caused by little contact between the decomposing HR and the soil underneath (Jones et al., 1999), despite the harvesting procedure itself causing some incorporation of the HR into the topsoil (Nambiar, 1996; Noormets et al., 2015). Importantly, HR incorporation into the topsoil increases nutrient mineralization, and as such, it seems to favor eucalypt growth in subsequent rotations (Jones et al., 1999; Madeira et al., 2010). However, despite the importance of HR as a nutrient source in low-fertility soils (Laclau et al., 2010), the generalization of HR incorporation should be further evaluated across southeastern Brazil, where eucalypt plantations are established in areas with very contrasting soil types (Gonçalves et al., 2013). This may be a concern because of the general low cation exchange capacity (CEC) of tropical soils (Sanchez et al., 1992), and HR incorporation would increase the decomposition rate and nutrient release. Under such circumstances, potential losses of nutrients through leaching cannot be ruled out (Nzila et al., 2002). Furthermore, incorporating HR into the topsoil also could stimulate the decomposition of SOC, which is an important component to be taken into account for appropriate management of forest plantations (Madeira et al., 1989; Zinn et al., 2002; Noormets et al., 2015). Therefore, by evaluating the effect of HR incorporation and its maintenance on the soil surface on the overall decomposition rate could help in the decision-making in terms of managing HR in forest plantations.

The objectives of this study were to investigate the decomposition of eucalypt HR as affected by three critical forest practices: HR disposal (mixed into the topsoil or left on the soil surface), bark management (removal or maintenance) and nitrogen fertilization. Additionally, we investigated to what extent HR decomposition is affected by soil properties, temperature and precipitation. In order to address our research questions, we evaluated the decomposition rate of eucalypt HR by performing field experiments during 3 years in 10 locations across southeastern Brazil.

2. Material and methods

2.1. Sites description

In the states of Bahia and Espírito Santo, the experiments were installed at Eunápolis (EUN) and Aracruz (ARA), respectively, and both areas are located near the Atlantic Ocean on coastal plain soils. The main difference among these areas concerns the total precipitation, which is higher in EUN than in ARA, while in both regions the predominant soils under eucalypt plantations are Ultisols and Oxisols. We also selected areas at Virginópolis (VIR), Belo Oriente (BOR), João Pinheiro (JPI), Três Marias (TMA), Curvelo (CUR), Itamarandiba (ITA) and Vazante (VAZ), all in Minas Gerais state, and one experimental area was selected at Mogi Guaçu (MGU) in the state of São Paulo. The total precipitation in the areas selected in Minas Gerais and São Paulo has a similar range (from 1300 up to 1600 mm $year^{-1}$). In these states, eucalypt plantations are established in soils with heterogeneous texture, occurring in areas with contrasting relief, and the soils selected for our study are Oxisols and Entisols. The EUN, ARA, VIR, BOR and MGU sites are located within the Mata Atlântica biome, while JPI, TMA, CUR, ITA, and VAZ are located within the Cerrado biome (savanna-like). These areas were selected due to their importance for forestry across southeastern Brazil, accounting for more than 60% of the area under eucalypt plantations (Gonçalves et al., 2013).

The climate datasets were collected at each site during the 3-year period in which the HR underwent decomposition in the fields. This aspect is very important because the experiments could not be installed at the same time in all sites and using historical datasets for climate variables might have been misleading. Soil properties were determined from samples collected during the installation of the experiments. At each site, the sampling consisted of collecting 32 subsamples within the 0–5 cm depth, which were combined to yield a composite sample (see Section 2.2 for further details). The pH of the soil was determined in water (10 g soil into 25 mL of deionized water) using a pH meter (Prolab-PHB 500). The soil texture was assessed by wet sieving to separate the sand fraction, and the silt and clay fractions were separated by the pipette method. In addition, the SOC fractions were separated through physical fractionation (Cambardella and Elliott, 1992). Accordingly, 10 g of fine earth (<2 mm) were dispersed into 30 mL of hexametaphosphate (5 g L^{-1}) for 16 h with continuous stirring, followed by wet sieving to obtain the particulate organic matter (POM) fraction (>53 μm) and the mineral-associated carbon (MAC) fraction, that is, the organic matter within the silt and clay-size particles (<53 μm). The C content of each fraction was determined by dry combustion in a continuous flow isotope ratio mass spectrometer (GSL 20–20, Sercon, Crewe, UK). The exchangeable Ca and Mg were extracted by KCl 1 mol L^{-1} (10 cm^3 soil into 100 mL solution), and their concentrations were determined by atomic absorption spectrometry in a Varian Spectra AA (model 220F). The same KCl extract was used to determine the concentration of exchangeable Al, which was determined by the titration method, using NaOH 0.025 mol L^{-1}. P and K were extracted using Mehlich-1, by mixing 10 cm^3 of soil with 50 mL of the extractant for 20 min under continuous stirring.

2.2. Experimental setup

In order to obtain a homogeneous material with enough quantity for installing the experiments in all 10 sites, a 2-year-old