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Fine root production and turnover in Brazilian *Eucalyptus* plantations under contrasting nitrogen fertilization regimes

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ABSTRACT

Nitrogen fertilization increased largely over the last decade in tropical eucalypt plantations but the behaviour of belowground tree components has received little attention. Sequential soil coring and ingrowth core methods were used in a randomized block experiment, from 18 to 32 months after planting *Eucalyptus grandis*, in Brazil, in order to estimate annual fine root production and turnover under contrasting N fertilization regimes (120 kg N ha^{-1} vs. 0 kg N ha^{-1}). The response of growth in tree height and basal area to N fertilizer application decreased with stand age and was no longer significant at 36 months of age. The ingrowth core method provided only qualitative information about the seasonal course of fine root production and turnover. Mean fine root biomasses (diameter <2 mm) in the 0–30 cm layer measured by monthly coring amounted to 0.91 and 0.84 t ha^{-1} in the 0 N and the 120 N treatments, respectively. Fine root production was significantly higher in the 0 N treatment (1.66 t ha^{-1} year^{-1}) than in the 120 N treatment (1.12 t ha^{-1} year^{-1}), probably as a result of the greater tree growth in the control treatment throughout the sampling period. Fine root turnover was 1.8 and 1.3 year^{-1} in the 0 N and the 120 N treatments, respectively. However, large fine root biomass (diameter <1 mm) was found down to a depth of 3 m one year after planting: 1.67 and 1.61 t ha^{-1} in the 0 N and the 120 N treatments, respectively. Fine root turnover might not be insubstantial in deep soil layers where large changes in soil water content were observed.

1. Introduction

Eucalyptus is the most widely planted tree genus in the tropics (FAO, 2001). Empirical observations, as well as studies of biogeochemical cycles and modelling approaches, show a general upward trend in nitrogen (N) fertilizer requirements over successive rotations in commercial eucalypt plantations (e.g. Gonçalves et al., 2004; Laclau et al., 2005). Tree response to N fertilizer inputs is still inaccurately predicted and process-based studies are required to improve site-specific N fertilizer inputs (Smethurst et al., 2004). The effects of water and nutrient supply on aboveground tree growth have been extensively investigated (Gonçalves et al., 2004; Stape et al., 2004) but few studies have dealt with the effects of silvicultural practices on fine root development in eucalypt plantations (e.g. Mello et al., 2007). Even if the amounts of fine root necromass and aboveground litter are likely to be of the same order of magnitude in forest ecosystems (Raich and Nadelhoffer, 1989), studies quantifying fine root mortality are scarce and mainly limited to temperate forests (Gill and Jackson, 2000; Johnsen et al., 2005). Such a lack of information, although it is essential to gain an insight into the response of forests to environmental changes, is partly due to difficulties in measuring fine root mortality and more generally fine root turnover (Vogt et al., 1998). So far, no consensus exists on the best method for measuring fine root production and then calculating fine root turnover and it is now well recognized that a combination of different methods may provide the most reliable results (Vogt et al., 1998; Hertel and Leuschner, 2002; Hendricks et al., 2006). Sequential coring (Persson, 1978) is the most common method used. That method has been greatly improved by including the use of "compartment flow" techniques (Santantonio and Grace, 1987) or "decision matrix" calculations (Fairley and Alexander, 1985) to take into account the decomposition rates of dead fine roots (Vogt et al., 1998). The sequential coring method is often (but not always) associated with ingrowth core measurements, where root-free soil cores are installed in mesh bags in the soil and sampled successively over at least a growing season (Makkonen

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and Helmisaari, 1999; Hertel and Leuschner, 2002; Godbold et al., 2003; Ostonen et al., 2005; Hendricks et al., 2006). Ingrowth cores are effective in ecosystems where root growth is rapid, e.g. wet tropics (Cuevas and Medina, 1983). However, the disturbance of root-free soil and the severing of roots when mesh bags are installed are likely to modify fine root dynamics considerably (Vogt et al., 1998; Hertel and Leuschner, 2002). Other method commonly used over the last decade is the minirhizotron technique which enable direct root measurements (Majdi, 1996) and the quantification of total belowground carbon allocation (e.g. Raich and Nadelhoffer, 1989). Even though comparisons have shown the relevance of these methods in various situations, bias inherent to each method still remains (Majdi, 1996; Nadelhoffer, 2000; King et al., 2002; Hendricks et al., 2006). More recently, promising methods using stable or radiocarbon isotopes have been developed, but they have only yet been used in a small number of study sites (Gaudinski et al., 2001; Giardina et al., 2004; Johnsen et al., 2005; Joslin et al., 2006).

Eucalyptus plantations in the tropics are simplified forest ecosystems where relevant estimations of fine root turnover can be made, despite the uncertainties inherent to each method. The understorey is eliminated by herbicide application and monospecific eucalypt stands are usually installed in highly weathered deep and relatively homogeneous soils. The effects of N fertilizer inputs on fine root production and turnover were studied in Brazilian *Eucalyptus grandis* (Hill ex Maid) stands, from 18 to 32 months after planting. Nutrient cycling processes are established during that period (Laclau et al., 2003), and thereafter trees are usually much less responsive to fertilizer inputs (Smethurst et al., 2004; Gonçalves et al., 2004).

The aim of this study was to quantify the effects of N fertilization on fine root production and turnover during the early growth period of *E. grandis* stands, comparing the estimations given by two direct methods (sequential coring and ingrowth cores). A better understanding of fine root dynamics in *Eucalyptus* ecosystems is essential for gaining an insight into the effects of fertilization regimes on the biogeochemical cycles of nutrients.

2. Materials and methods

2.1. Study area

The study was carried out at the Itatinga Experimental Station (University of São Paulo, São Paulo State, Brazil) on a 68-ha experimental watershed (23°02′S; 48°38′W) covered with eucalypts. The mean annual rainfall over the 15 years prior to this study was 1360 mm and the mean annual temperature was 19 °C with a seasonal cold period from April to August (Fig. 1). The relief of the study area was typical of the São Paulo Western Plateau, with a soft wavy topography. The experiment was located on a hill top (slope <3%) at an elevation of 850 m. The soils were very deep ferralsols (>15 m) developed on cretaceous sandstone, Marília formation, Bauru group, with a clay content ranging from 14% in the A_1 horizon to 23% in deep soil layers. The mineralogy was dominated by quartz, kaolonite and oxyhydroxides, with acidic (pH between 4.5 and 5) soil layers containing low concentrations of nutrients. Soil nitrogen content in the 0–5 cm layer was 1.56 g kg^{-1} on average (n = 9) before installation of the experiment. The ECEC ranged from 0.5 to 3 $cmol_c\ kg^{-1}$ in the top 3-m soil layers and the amounts of exchangeable bases were lower than 0.2 $cmol_c\ kg^{-1}$, below a depth of 5 cm.

The experimental area was covered by *Eucalyptus saligna* (Sm.) plantations managed as a coppice, which received no fertilizer from 1940 to 1997. Nutrient export in harvested boles every 5–7 years had led to an expectation that trees would respond to N inputs.

2.2. Experiment

The experiment was launched in an *E. saligna* stand planted in June 1998, where relatively small amounts of fertilizer had been applied (one application of 300 kg ha^{-1} of NPK 10:20:10 at planting). The stand was harvested at 6.5 years of age (February 2004), and herbicide was applied to the stumps to prevent further coppicing. Boles were removed from site and harvest residues were

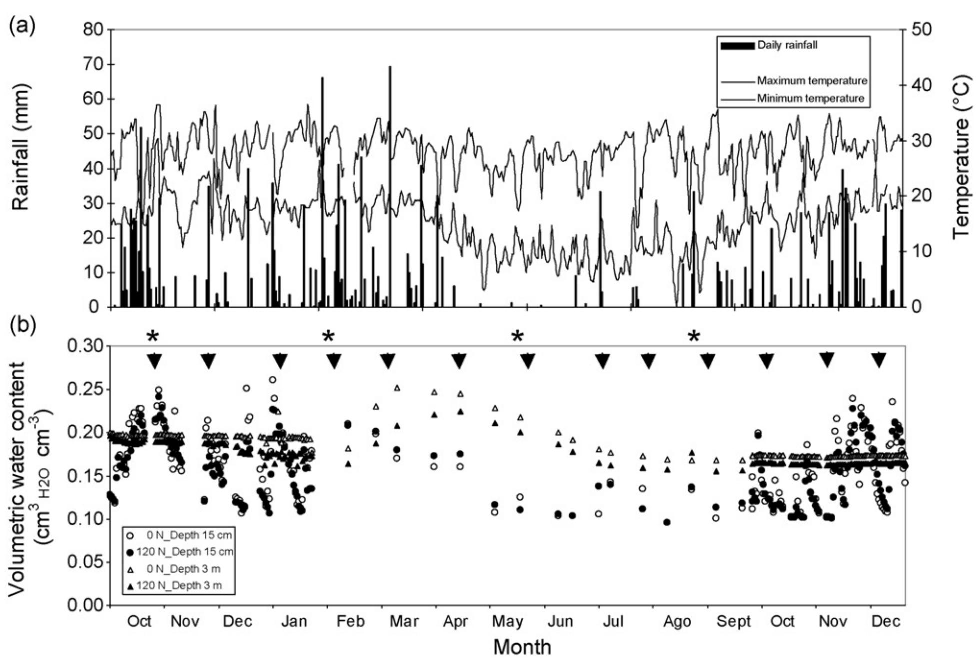

Fig. 1. Daily rainfall and air temperature over the period of sequential coring, from 1 October 2005 to 31 December 2006 (a) and time course of soil water content at the depths of 15 and 300 cm (b). Each value is a mean of two measurements per day by three TDR probes (minitrase, soilmoisture) in each treatment except from February to September 2006 where measurements were made fortnightly. Arrows (↓) indicate the sampling dates for the sequential coring method and stars (*) for the ingrowth bag setup.