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Soil quality of first rotation *Eucalyptus* stands growing on an Andisol using soil microbial indicators

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Abstract

The potential soil biological change due to the establishment of Eucalyptus plantations in volcanic soils has not been reported. The objective of this research was to assess the soil quality of *Eucalyptus* stands growing on a volcanic ash derived soil, compared with a natural forest (Nat-forest, control) and a *Pinus radiata* stand, previously established to the *Eucalyptus* stand. A complete randomised design was established (n=4) within Nat-forest and commercial plantations. Soil samples (10 cm) were taken in autumn, to measure soil microbial biomass (C_{biom}) by soil fumigation-extraction, and CO_2-C respiration (C_{min}) from soil microorganisms by soil incubation. Metabolic quotient (q_{met}) was calculated to compare ($p \leq 0.05$) the microbial efficiency of the soil biomass between treatments. As expected, Nat- forest showed the largest C_{biom} and C_{min} ($p \leq 0.05$). However, no differences were found between *E. globulus*, *E. nitens* and *P. radiata* ($p \leq 0.05$). The low C_{biom} and C_{mic} in *Eucalyptus* stands might be attributed to the effect of recalcitrant inputs of C from the previous pine plantation, although the efficiency of the soil microbial population (q_{met}) was not affected ($p \leq 0.05$) by the C quality of the plantations. Thus, it seems that *Eucalyptus* stands are not entirely detrimental to the soil quality of volcanic soils of temperate forest ecosystems.

Keywords: Soil organic matter, carbon mineralization, forest soil, andisol.

1. Introduction

Eucalyptus nitens and *Eucalyptus globulus* are the main plant *Eucalyptus* species planted in Chile due to their high production capability associated with tolerance to low temperatures. *E. nitens* in particular shows volumetric increments of 30 to 45 m^3 ha^{-1} y^{-1}, and is better adapted to low temperatures than *E. globulus*. On the other hand, volume growth rate of *E. globulus* is in the range of 20 to 25 m^3 ha^{-1} y^{-1}, and naturally losses part of its branches during its growing cycle (Muñoz *et al*., 2005). Aiming to improve stand yield, forest management is similar for both species, which consists of soil tillage, N applications, and control of invasive vegetation (Guerra and Puentes, 2002). However, there is no information about how these practices affect soil quality in the South of Chile.

Soil microbial biomass has been used to assess soil quality under *Eucalyptus* stands under different conditions in both tropical and subtropical regions, i.e., evaluating the impact of machinery on soil tillage (Ilstedt *et al*., 2006), assessing land use from grassland to *E. grandis* (Sicardi *et al*, 2004), and assessing the effect of native forest, regenerated native and *Eucalyptus* forest (Behera and Sahani, 2003). However, as far as we know, potential soil change due to the establishment of *Eucalyptus* plantations in volcanic soils has not been reported.

The piedmont region between 36ºS and 38ºS has a large potential to sustain *Eucalyptus* plantations (more than 250000 ha planted, INFOR, 2008), but the volcanic soils where *Eucalyptus* is being planted is in several cases susceptible to being degraded, particularly if soil C stock is depleted (Dube *et al*., 2009). Despite progress on management of *Eucalyptus* stands, the role of soil in vulnerable pre-mountain ecosystems of South America has not received enough attention. Therefore, in order to evaluate the soil quality of Andisols, this research assessed an active fraction of the organic matter -the soil microbial biomass, under *Eucalyptus* plantations located at the piedmont of the Andes mountains (South of Chile).

2. Materials and methods

The study area was located at the piedmont of the Andes mountains of Chile (460 m.a.s.l., latitude 37º 32' S, longitude 71º 55' W). The top 10 cm of Santa Bárbara soil (Typic Haploxerands) showed characteristics of Andisols (Shoji *et al*., 1993) such as, high organic matter content (6 to 17%) and low bulk density (0.7 to 1.0 g cm^{-3}), low pH (5.4 to 5.9), and low available P (6.2 ppm). The climate of this region is temperate-Mediterranean (Novoa and Villaseca, 1989). The native forest in hydromorphic conditions of this region has been progressively replaced by *Pinus* and *Eucalyptus* plantations, as well as by arable crops. Therefore, we assessed soil microbial biomass within natural forest, *Pinus radiata*, *Eucalyptus nitens* and *Eucalyptus globulus* plantations. The native forest (26 ha) is a renewal of transitional evergreen-sclerophyll forest, occasionally affected by human interventions. The *E. nitens* (3 ha) and *E. globulus* (3 ha) stands in site were planted on a square grid design at a density of 1600 stems ha^{-1} (1996), over interspaced rows left by the previous *Pinus radiata* plantation. After six years of plantation, the growing parameters of the stands of *E. nitens* and *E. globulus* were similar, as shown in Table 1.

Table 1. Growing parameters of *Eucalyptus* stands planted on a volcanic soil at the South-central piedmont of Chile.

Dasometric index	*Eucalyptus nitens*	*Eucalyptus globulus*
Diameter breast height (cm) Total height (m)	8.18	8.70
Canopy diameter (m)	12.85	10.50
Canopy length (m)	0.45	0.60
Dominant height (m)	12.25	13.57
Volume (m^3 $stem^{-1}$)	24.13	21.54
	0.14	0.14

Lowercase letters across the rows correspond to statistical differences between treatments using Tuckey test ($p \leq 0.05$).

Soil samples were taken at 10 cm depth of the topsoil in autumn (2004) from experimental plots (25m x 10m) arranged in a complete random design, with four replicates (n=4). After collection, soil samples were stored at 4ºC until analysis. Prior to soil microbial analysis, soils were thoroughly mixed and sieved at 2 mm, and roots and gross plant/tree residues were removed from the samples.

Soil microbial biomass (C_{biom}) was measured using the fumigation-extraction method with N-ninhydrine reagent (Joergensen and Brookes, 1990). Samples were adjusted to 25% of water capacity and 25 g of soil were fumigated (in three replicates) whilst another portion of the same weight was used as a control (non-fumigated, three replicates). The fumigation was carried out applying ethanol-free $CHCl_3$ on the samples for 24 hours at 25ºC. The fumigant was removed, and soil samples were extracted with 100 mL of 0.5 M K_2SO_4, shaken for 30 min and centrifuged at 2000 g for 5 min. Soil extracts were filtered (2.5 µm), and aliquots of 2 mL were transferred to 50 mL test tubes and 1 mL of ninhydrin reagent was added and mixed, to be placed afterwards on a boiling water bath for 25 min. Samples were cooled and 20 mL of 50% ethanol was added. Absorbance (570 nm) of the samples and blanks (0.5 M K_2SO_4) were measured in a spectrophotometer (Perkin Elmer, Junior Model 35). A standard solution of L-leucine at different concentrations (0, 2.5, 5, 7.5, 10, and 15 g µg N mL^{-1}) was used to plot a calibration curve against the measured absorbance values to obtain ninhydrin reactive N. C_{biom} was calculated as C_{biom} = 31 x ninhydrin-N (Ocio and Brookes, 1990).

Microbial activity was measured as CO_2-C evolved (C_{min}) after the soil was incubated at 22ºC for 10 days (Alef and Nannipieri, 1995) and three sub-samples (25 g) from each field repetition were individually incubated in a sealed glass container (capacity of 1 L) including an alkaline solution (0.5 M NaOH). At the end of the incubation period, CO_2-C was measured by removing the alkaline trap, adding $BaCl_2$ and titrating with 0.1 N HCl. The metabolic efficiency of the soil microbial biomass (q_{met}) was evaluated as the ratio between soil microbial respiration and the microbial biomass (Xu *et al*., 2006).

Analysis of variance (F test) for complete randomised design was applied to assess soil microbial variables.

3. Results and discussion

C_{biom} showed its largest value ($p \leq 0.05$) under Nat-forest soil and no differences between pine plantation and species of *Eucalyptus* were recorded (Table 2). Similar values have been found for temperate natural forests elsewhere (Saviozzi *et al*., 2001), whilst C_{biom} from *Eucalyptus* soil was in the range of reported values for non volcanic soils (Mendham *et al*., 2002).

Soil respiration followed a similar trend, Nat-forest > *E. nitens* > *E. globulus* > P. *radiata*, whilst the q_{met} showed no statistical differences between the stands and the Nat-forest (Table 2).

Table 2. Soil microbial and metabolic activity in natural forest and *Pinus* and *Eucalyptus* stands in the study area.

Parameters	**Natural forest**	**Pinus radiata**	**Eucalyptus nitens**	**Eucalyptus globulus**
Soil microbial biomass (μg C g soil^{-1})	1333.60 a	391.55 b	498.7 b	504.07 b
Soil microbial respiration (μg CO_2-C g soil^{-1})	216.47 a	83.02 b	102.61 b	86.23 b
Metabolic quotient (μg CO_2-C mg C_{biom}^{-1})	16.66 a	23.81 a	20.81 a	16.74 a

The large C_{biom} and soil microbial activity at Nat-forest is likely due to the diversity of organic inputs from the understory vegetation that improves litter quality (Jia *et al*., 2005). In contrast, C_{biom} in soils under plantation might be decreased by the effect of pine tree residues that have a detrimental effect on the microbial activity. Pine litter contains more recalcitrant compounds as the stand becomes older (waxes, lipids, cutins and resins), and difficult to be metabolised by soil microorganisms (Gartzia *et al*., 2011). Despite no significant differences ($p \leq 0.05$) in C_{biom} and C_{min} between *Eucalyptus* and *Pinus* stands, these indicators showed some increase under *Eucalyptus* stands.

The Nat-forest showed the smaller q_{met} indicator. The trend was Nat-forest < *E. globulus* < *E. nitens* < *P. radiata*, but there were no differences between treatments ($p \leq 0.05$) (Table 2). Despite statistical differences, the soil under *E. globulus* showed the same q_{met} coefficient as Nat-forest, which indicates an efficient microbial biomass community, capable of incorporating and maintaining larger C substrates into their metabolic processes against losses through respiration, better than *E. nitens* and *P. radiata* stands. Pine residues might influence an input of low metabolisable C compounds (Dube *et al*., 2009) to this first rotation of *Eucalyptus,* but the microbial activity seems to recover with time. Perhaps at the end of the first rotation of *Eucalyptus*, the organic matter provided by the above biomass and root exudates might better define the quality of *Eucalyptus* litter, and the growth of the microbial biomass component.

4. Conclusions

The biological quality of the pre-mountains Andisols was affected by *E. nitens* and *E. globulus* stands, as shown by the small size of the microbial biomass pool and its respiration activity when compared with a natural forest. However, the biological indicator q_{met} between the plantations and the natural forest did not show differences ($p \leq 0.05$). Thus, it seems that *Eucalyptus* stands have at some extend, a detrimental effect on the soil quality of Andisols of temperate forest ecosystems.

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