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# Temporal variations of rhizosphere and bulk soil chemistry in a Douglas fir stand

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## Abstract

Rhizosphere soil can play a central role in the maintenance of the soil–plant system and influencing the biogeochemistry of forest ecosystems. However, rhizospheric studies *in situ* to understand the ecosystem functions are still lacking. Therefore, the objectives of the present study were to examine the differences in the chemical properties such as the pH, organic C, exchangeable base cations ($EBC = Mg^{2+} + Ca^{2+} + K^{+}$), exchangeable acidity and cation exchange capacity (CEC) of three soil fractions (Bulk, B; Rhizosphere, R and Rhizosphere Interface, RI) and the evolution of chemical properties of soil samples collected in March and June from a Douglas fir ecosystem located in the Beaujolais Mounts in France.

Most of the variables measured (organic matter, CEC and EBC) increased significantly in the same order ($B < R < RI$), indicating that the rhizosphere was a favorable interface for tree nutrition. These processes were more pronounced in June than in March, as the temperature and biological activities are normally higher in June than in March. The temporal variations of Al charge in R and B seem to depend on $OH^{-}$, organic complexation and $H^{+}$ production by roots and/or the organic matter degradation in the bulk soil. In the rhizosphere, the $H^{+}$ or $OH^{-}$ production depends on the N cycle. The results of this study and the support of independent mineralogical study using the same soil fractions, and of other field studies on the same site have all pointed at the importance of rhizosphere as an excellent indicator for the understanding of the ecosystem dynamics in both short- and long-term.

*Keywords:* Chemical properties; Cationic exchange capacity; Rhizosphere; Temporal variation; Soil; Forest ecosystem; Nutrient; Aluminum

## 1. Introduction

The rhizosphere, defined as the volume of soil influenced by root activity, differs in many aspects from the bulk soil due to the root uptake (water and nutrients), the root exudates, the root respiration and the higher microbial and fungal activity. The evidence of these profound chemical changes that occur in the rhizosphere have been reviewed by several authors in recent years (e.g. Curl and Truelove, 1986; Darrah, 1993; Marschner, 1995). In this zone, the weathering rate of soil minerals can be increased due to root and microflora activity and that can be manifested by, for example, pH decrease, higher organic acid production or differences in the oxydo-reduction potential (April and Keller, 1990; Hinsinger et al., 1992; Drever, 1994). These root effects on soils suggest to some investigators that soil can be considered, in part, as a product of plants and soil biota (Van Breemen, 1993).

In spite of the small volume that the rhizosphere occupies in the mineral soil, it plays a central role in the maintenance of the soil–plant system and influence the biogeochemistry of forest ecosystems (Gobran et al., 1998). However, *in situ* rhizospheric studies aimed at understanding ecosystem functions such as nutrition or aluminum toxicity are still lacking. This could be due to the complex nature of the ecosystem conditions where the dynamic nature of the ecosystem functions controlling the performance of plant, especially during the growing season, cannot be mimicked by experimental controlled conditions. Therefore, there is a strong need for more ecosystem studies

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geared to integrate mechanisms controlling the functional relationships between soil–plant–microorganisms. Apart of the field studies conducted and reviewed by Gobran et al. (1998, 2005) on coniferous forests growing on podzols to fully understand rhizosphere processes *in situ*, and Séguin et al. (2004) who studied extractable metal in the rhizosphere of forested soil, literature lacks greatly such studies under different climates and species. As rhizosphere is the soil that is influenced by the plant activities (above- and below-ground), it is hypothesized that rhizosphere must reflect the behavior of the plant during the active growing season. For example, biological activity in the rhizosphere including the dynamics of fine root growth (Ponti et al., 2004) and the vast dynamic of nutrient uptake by roots and their exudates during the growing season ought to be reflected by vast changes in the rhizosphere.

The objectives of this study were to 1) examine *in situ* in a forest site covered by a stand of 45-year-old Douglas fir the extent to which the biological activity can modify rhizosphere chemistry, and 2) relate the chemical changes in the three soil fractions (B, R and RI) in three different horizons to temporal effects occurring during March (M) and June (J), where biological activity changes drastically.

## 2. Materials and methods

### 2.1. Ecosystem description

A 45-year-old monospecific stand of Douglas fir (*Pseudotsuga menziesii* (Mirb) Franco) on the Beaujolais Mounts in France (46°30′N. 4°38′E) was chosen. This together with other that are covered by stands of 20 and 60 years old have been under intensive monitoring studies during 7 years (1993–1999). The chemical data obtained on the rhizosphere in this present study could be discussed in the light of the data obtained at the ecosystem scale. The chosen site is located at an altitude of 780 m on a gentle slope (<10°). Average annual air temperature is 7 °C and annual rainfall averages 1000 mm. The humus was a moder type and the soil was a typic Dystrochrepts (Soil Survey Staff, 1998) developed from a consolidated volcanic tuff dating from the upper visean (Ezzaïm et al., 1999a). The stocks and fluxes of elements in the vegetation and the soils were quantified in the chronosequence of three stands (Marques et al., 1996, 1997; Ranger and Turpault, 1999). The potential mineralizing and nitrifying capacity of the soil were also determined (Jussy et al., 2000). It is necessary to mention here that the mean annual flux of $N–NO_3^-$ in the soil solution of the studied site represents 90% and 93% of total N at depths of 15 and 30 cm, respectively. The studies performed by Ezzaïm et al. (1999b) showed that weathering processes at this site have lead to a poor soil in nutrients from a relatively rich rock, to acidic and under saturated soils and to loamy soils (Table 1). Although chemical analysis of tree leaf does not show any nutrient deficiency, the nutrient budgets calculated for the whole stand was found negative for major cations like Ca, Mg and K (Ranger and Turpault, 1999). However, the deficit of K was less then those of Ca and Mg. Such deficits seem to decrease with the stand age, particularly K in stand of 60 years old (Ranger and Turpault, 1999). In addition, the chemistry of rhizosphere solutions sampled at three depths (0–20; 20–40 and 40–60 cm) from the same site in March 1999 was investigated and showed that the concentration of all elements increased in the rhizosphere solutions as compared to the bulk soil solutions, except for P (Turpault et al., 2005).

### 2.2. Soil sampling

A representative area of 42 × 30 m was selected and divided into small subsections of 6 × 6 m. At the intersections between the grid formed in this manner, a systematic soil sampling was performed, except in places where obstacles such as tree trunks and stumps were in the way. Thirty soil pits of 30 cm width × 70 cm length were dug in both the beginning of March and end of June 1998. All the pits were filled up again with the same soil sampled from each layer systematically under the humus layer from layer 1 (0–5 cm), layer 2 (5–15 cm) and layer 3 to limit soil perturbation. The pits sampled in June were dug at 50 cm and at the top of the slope of the old pits dug in March. At each sampling time, 30 mineral soil samples were taken (15–30 cm). At the site, roots <2 mm were carefully removed by hand and the adherent soil aggregates >1 cm on the root were discarded. The soil fraction that was free of roots was collected to give the bulk soil fraction (B). To limit the root–soil interactions after sampling, the roots with the adherent soil aggregates <1 cm were immediately dried in a steam-air dryer at a maximum temperature of 30 °C. The soil fraction that was detached from the roots after drying was collected to give the

Table 1
Description and selected properties of the soil (<2 mm) used in this study

| Profile | Depth | pH | Cation exchange capacity | Exchangeable acidity | Organic C | Oxalate extractable | | | Clay | Silt | Sand |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Fe | Al | Si | | | |
| | cm | $H_2O$ | $cmol_c kg^{-1}$ dry soil | | $g\ kg^{-1}$ dry soil | | | | | | |
| A1 | 0–10 | 4.4 | 10.2 | 9.0 | 3.3 | 4.9 | 4.7 | 0.9 | 194 | 352 | 454 |
| A1/Ap | 10–20 | 4.5 | 6.1 | 5.5 | 2.8 | 4.3 | 4.5 | 0.7 | 222 | 380 | 399 |
| Ap2 | 20–30 | 4.5 | 5.8 | 5.3 | 2.2 | 3.6 | 2.8 | 0.3 | 191 | 396 | 413 |
| A/(B) | 30–45 | 4.5 | 5 | 4.5 | 0.9 | 3.8 | 2.6 | 0.2 | 186 | 390 | 425 |
| (B)1 | 45–65 | 4.7 | 4.7 | 4.3 | 0.4 | 2.7 | 2.1 | 0.2 | 181 | 374 | 446 |
| (B)2 | 65–85 | 4.8 | 4.1 | 3.6 | 0.2 | | | | 120 | 334 | 546 |
| (B)/C | 85–110 | 4.8 | 4.6 | 4.2 | 0.2 | 1 | 0.9 | 0.1 | 87 | 321 | 592 |
| C | 110–120 | 5.2 | 5.4 | 3.9 | 0.2 | 1.3 | 0.8 | 0.1 | 125 | 344 | 531 |