Soil solution monitoring in a network of forest ecosystems under temperate and tropical climates provides new insights on the current soil functioning

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Abstract
Medium term monitoring of forest soils in the temperate and the tropical environment allow us to show that soil solutions represent an efficient tool to assess the changes in current soil functioning because they are one of the most reactive components of the ecosystem. A conceptual model is proposed to gain insight into the interactions between soil solutions and the soil solid phase.

Several examples will be presented where soil solution monitoring was used to address specific ecological questions e.g. i- the influence of stand age on element leaching, ii- the effects of tree species on current soil processes, iii- the Impact of tree species on the origin and on the dynamic of dissolved organic carbon in different soil solution types, iv- the effects of afforestation of herbaceous savannas with *Eucalyptus* plantations in Africa on the chemistry of superficial water, and, v the effects of fertilisation and/or liming on current soil functions.

Key Words
Soil solutions chemistry, soil processes, tree species changes, liming and fertilisation, tropics and temperate conditions

Introduction
Soil solution chemistry has been studied over the last twenty years with a similar experimental design installed in forest soils under temperate and tropical climates. These studies showed that soil solutions represent an efficient tool to assess the changes in current soil functioning because they are one of the most reactive components of the ecosystem. Nevertheless, soil solution chemistry results from complex interaction processes that are difficult to analyse on an individual basis, since they must take into account both sources (inputs of pollutants, organic matter mineralisation and mineral weathering) and sinks of elements (vegetation uptake and micro-organism immobilisation, physicochemical stabilisation processes).

A conceptual model is proposed to gain insight into the interactions between soil solutions and the soil solid phase. This model shows that specific investigations (using complementary techniques) are needed to sample the adequate solution for a specific purpose.

Soil gravitational solutions with short residence time in soils acquire their chemistry from rapid reactions (displacement of soluble compounds, ion exchange reactions). Chemistry of moderately fixed solutions results from exchanges between gravitational and strongly fixed solutions (diffusion, convection) and from the biological interactions, particularly plant-uptake. Strongly fixed solution chemistry reflects the sources of elements released by mineral weathering and organic matter mineralization in rather steady state conditions. Obviously, strong interactions exist with climate and biology, especially if the objective is the assessment of the characteristics of solutions where plant roots take up water and nutrients.

Comparing the three types of solutions in intensively monitored ecosystems demonstrated the importance of using a collector adapted to the processes studied: zero tension open plate lysimeters were suitable for drainage measurements while solutions extracted by centrifugation or displaced on soil columns represented the reactive solutions for both geochemistry and plant nutrition purposes (Ranger et al., 2001). Geochemical calculations validated the conceptual model using the relationship between dissolved silica representing the weathering rate and pH as a proxy of the solution reactivity.

Observations made on experiments monitored over 5-7 years, both on temperate and tropical sites, showed that the conceptual model describing the acquisition of soil solution chemistry was generic but that strong

differences appeared according to soil mineralogy. In moderately weathered soils under temperate climate, the concentrations of base cations increased with the residence time indicating that proton neutralisation altered the primary structures. Under tropical climate, the increase in residence time of solutions in highly weathered soils did not lead to an increase in base cation concentrations. In these soils, base cations mainly originated from atmospheric deposition and forest floor mineralization (Laclau et al., 2003, 2005, 2009). Whilst the concentrations of base cations in soils solutions collected by tension lysimeters in temperate forests were classically higher than in solutions collected by zero-tension lysimeters, the opposite was observed in tropical plantation forests.

Materials and methods

Several sites were monitored in France (Beech, oak, Spruce, Douglas fir, pine and fir plantations on acid environments) and in the tropics (Eucalyptus plantations on arenosoils of the coastal plain of Congo, oxisoils in the Sao Paulo estate) for periods ranging between 5 and 10 years. Meso- and pedo climate were monitored continuously. Carbon and element stocks were quantified and fluxes between compartments were estimated using the concentration of nutrients in solutions and a hydric model.

Usually different types of lysimeters were used to collect gravitational water (Zero Tension Lysimeters), weakly fixed soil solution (porous cup lysimeters) and fixed solution 'extraction by centrifugation). Collection of solutions occurred weekly (tropics) or monthly (temperate sites). Major elements were investigated for total content and/or for chemical species (N, Al).

Results and discussion

Several examples will be presented where soil solution monitoring was used to address specific ecological questions:

- influence of stand age on element leaching: soil solution monitoring over 5-7 years showed very divergent figures according to species, soil types, geographic situations and past land use histories. The parameters controlling element leaching were identified in each situation studied (Dambrine et al., 1995, Ranger et al., 2002, Legout, 2008).
- effects of tree species on current soil processes: changing the tree species strongly modified the biogechemical functioning. In very poor soils, tree species promoting nitrification can lead to high concentrations of toxic Al in solutions while tree species which inhibit nitrification were characterized by the leaching of large DOC concentration from forest floor (Titeux et al., submitted).
- Impact of tree species on the origin and on the dynamic of dissolved organic carbon in different soil solution types. Use of UV absorption spectrophotometry made it possible to monitor 30 years after planting the influence of tree species on aromatic C content and related properties of DOC (Jaffrain et al. 2007).
- effects of afforestation of herbaceous savannas with *Eucalyptus* plantations in Africa on the chemistry of superficial waters: the solutions of these very poor soils did not greatly change after afforestation because *Eucalyptus* developed an efficient strategy to take up the nutrients, which mainly originated from organic matter decomposition and atmospheric depositions (Laclau et al., 2003; 2009).
- effects of fertilisation and/or liming on current soil functions: medium term effects of a limited soil enrichment largely modified soil solution chemistry in poor soils, but were not clearly detected on the solid phase. Indeed, elements like Ca are intensively recycled biologically and this process greatly reduces the risks of leaching of this element poorly retained in acidic soils.

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