



## A snapshot of soil water composition as an indicator of contrasted redox environments in a hedged farmland plot

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### ABSTRACT

While soil water composition has long been recognised as being related to soil type (characteristics of the horizons), the influence of structures resulting from agricultural activities (hedges, ditches, wheel ruts, etc) is still under discussion. This work was undertaken to show that a snapshot of spatial variability of the geochemical characteristics of soil water at the scale of a plot can improve our understanding of soil geochemistry in a farmland setting. We selected a 3 hectare hedged plot located on a hillside, limited by a stream and used as pasture where soils have developed in weathered gneiss. The water depth, electrical conductivity, major ions, temperature, pH, dissolved organic carbon (DOC) content, dissolved oxygen content, fluorescence, alkalinity,  $\text{Fe}^{2+}$ ,  $\text{Mn}^{2+}$ ,  $\text{NO}_2^-$ ,  $\text{Fe(III)}$  and  $\text{F}^-$  contents were measured in 62 auger holes randomly drilled on the site. Four sectors were identified in order to describe the distribution of the main geochemical parameters. Electrical conductivity and some major ions, especially sulphate, had larger concentrations near hedges where oxic conditions prevailed. These features were attributed to the impact of the linear anthropogenic network on the circulation of subsurface soil waters and evapo-transpiration and represent sector I. Dissolved Mn was an indicator of well channelled runoff subsurfaces facilitating the circulation of more highly reducing water (sector III), while DOC probably marked areas drained less well, with a prolonged contact time between soil solutions and organic topsoil horizons (sector II). The presence of dissolved Mn and Fe(II) indicates bottomland anoxic conditions (sector IV). It is concluded that a survey of the chemical composition of soil water may be a direct approach to show the influence of permanent structures on current soil properties and dynamics.

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### 1. Introduction

Formation of soils results from the cumulative effect over time of chemical fluxes responsible for lateral and vertical differentiations. Numerous studies have addressed the spatial variability of chemicals in solid phases of soil resulting from these fluxes (Arrouays et al., 2000; Bourennane et al., 2003; McBratney et al., 2003). In order to discuss the present geochemical dynamics of soils and possible transport of pollutants, however, solute transport must be considered in soils that in most cases are now affected by agricultural practices with their consequences at different scales (Bruand, 2005). Current geochemical dynamics of soils can be discussed using soil water contributions to streamflows. This enables the analysis of the spatial and temporal variability of chemical processes in soils according to the size of the catchment contributing to streamflows (Avila et al., 1995;

Curmi et al., 1997). The seasonal variability of chemical interactions between solutes and solid phases in soils may also be surveyed over time by sampling soil water at different locations (Gasser et al., 1994; Biddle et al., 1995; Bourrié et al., 1999; Lilienfein et al., 2000). On the other hand, with the exception of a study by Manderscheid and Matzner (1995) averaging annual fluxes through soils, there are a few studies on the spatial variation of soil solution chemistry at the catchment scale, especially at the plot scale which is the basic land unit in terms of agricultural activities.

At the plot scale, the composition and circulation of water are related to the 3D distribution of horizons and their respective characteristics, but also to anthropogenic structures such as hedges, ditches or wheel ruts if present. Water circulation and especially lateral underflow above clayey horizons when present, can induce specific chemical transfers and reactions, especially in hydromorphic soils (Bourrié et al., 1994). The aim of this work was to show that a snapshot of the spatial variability of geochemical characteristics of soil water can improve our understanding of soil dynamics in land plots with non-uniform areas such as those encountered in landscapes marked by hedgerows.

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## 2. Materials and methods

The site is located on the Aigurande plateau in the French Massif Central, 10 km south of La Châtre (Indre) and was intensively surveyed by Salvador-Blanes (2002) in order to analyse the spatial distribution of major and trace elements in soil minerals along a toposequence. The approximated 3 hectare (ha) plot *Le Pré Neuf* is located on a hillside, used as pasture. Soils are Planosols (ISSS Working Group RB, 1998) developed on gneissic alterites and exhibit a stony horizon rich in Fe–Mn oxides overlaying a clayey B horizon (below 50 cm). Upper horizons are allocthonous and derived from colluvial materials of amphibolitic and gneissic origin. Colluvial materials differentiate into three horizons: a sandy-loam to clay-loam organic-rich A-horizon (25 to 30 cm thick) and two E horizons, one of them rich in concretions and gravels (Cornu et al., 2005). A seasonal water table is found within the surface horizons located above the B-horizon from December to May. The soil was drilled with a manual auger to the top of the B-horizon in 62 georeferenced points located on two grids (25×25 and 40×40 m cells) with about one sample per 300 m<sup>2</sup> (Fig. 1). The sampling campaign lasted for 3 consecutive days in winter. Sampling, field and laboratory analysis methods are detailed in the Supplementary file caption.

## 3. Results and discussion

### 3.1. Sampling quality and chemical consistency

Even in the lower part of *Le Pré Neuf* (Fig. 1), where soil waterlogging was maximized, water in the auger holes rose slowly, seeping both laterally and from the soil bottom layer with high permeability. Mixing with water from small superficial puddles responsible for the soggy ground aspect of the plot was negligible. Moreover, quasi-anoxia and a high Fe<sup>2+</sup> content of some samples indicated no mixing with superficial waters during sampling; this will be discussed in more detail below. Solutions sampled may be regarded as free-flowing soil waters as stated

by Avila et al. (1995). The chemical composition of the soil water was consistent with ionic balance (<5% for most samples), electrical conductivity and bulk basic redox rules.

Descriptive statistics and variography analysis were performed on the complete data set (Supplementary file), but since the gain for geochemical understanding of the soil water was small and a detailed account would exceed the scope of this study, the presentation of the results and their discussion focus on maps established for selected key parameters (Fig. 2). We plotted raw data with dot sizes proportional to analytical values rather than maps resulting from kriging since the experimental variograms of the data and their theoretical fitted models in some cases were too disparate for the required characteristics in order to accurately estimate spatial variability. Nevertheless, close relations between specific parameters were evident, for instance (i) electrical conductivity (Fig. 2a) displayed common patterns to ionic strength (Fig. 2b) and major ions, e.g. sulphate (Fig. 2e), (ii) dissolved oxygen-rich samples were also rich in nitrates (Fig. 2f and g), (iii) samples containing nitrites (Fig. 2h) had smaller oxygen and larger Mn<sup>2+</sup> contents (Fig. 2i) than other samples, (iv) the sample richer in Fe<sup>2+</sup> was quasi-anoxic (Fig. 2k), and (v) samples with higher dissolve organic carbon (DOC) gave higher fluorescence intensity (Fig. 2i and m) and contained low nitrate and dissolved oxygen contents, consistent with DOC accumulation in rather poor oxic conditions.

Several samples appeared to differ significantly from the surrounding samples: (i) W15 next to the hedge and south of the path (Fig. 1) showed high major ion concentrations, conductivity, pH and alkalinity (Fig. 2j and n), (ii) W4 and more clearly J5 at the slope bottom were the only Fe<sup>2+</sup> rich samples (2.6 mg L<sup>-1</sup> in J5) which were the least oxygenated, (iii) J5 was enriched in Si, Al and Fe(III) (13.4, 4.6 and 11.7 mg L<sup>-1</sup> respectively) compared to average values recorded (less than 9.1, 1.1 and 1.0 mg L<sup>-1</sup>, respectively). Site J33, next to the hedge north of the path, was a muddy hole with little free water rich in Si, Al and Fe(III) (14.8, 5.5 and 3.9 mg L<sup>-1</sup> respectively), probably due to the presence of colloids.

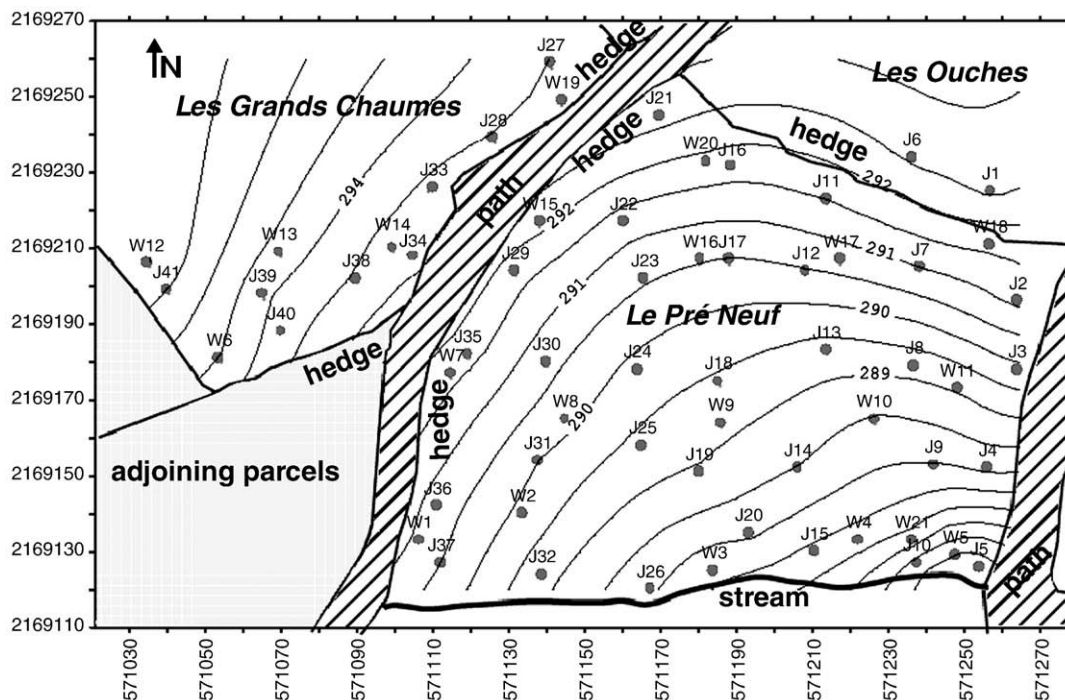


Fig. 1. Site and location of auger holes for water samples. Narrow lines are contour lines from 285 m (SE) to 296 m high (NW). Lambert metric coordinates are presented on the abscissa and ordinate.

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