

Mapping and monitoring issues of a forest soil network in Southern Belgium

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Abstract

Soil monitoring has become a rising concern during last decade in Europe. A Forest Soil Survey (FSS) is being implemented in Southern Belgium as a component of a forest observation and monitoring programme. An analysis of the monitoring network has been performed at mid-term of the first investigation stage in order to assess current soil conditions and the temporal evolution that can be detected in the future. The fertility status and major and trace elements in forest soils have been investigated at regional scale through uni- and multivariate statistical analyses of the 410 soil samples of the network. A performance analysis of the network has been realized regarding the capacity to detect evolution of soil parameters. The first results show a moderate to strong variability according to the variable considered. High levels of variability were attributed to the presence of carbonated parent material in a distribution largely dominated by detritic terrigenous rocks. The total contents in forest soils are mainly driven by pedo-geochemical background. The FSS allowed detailed mapping because there are clear convergences between spatial distributions of most of the elements and lithology or small natural regions. The levels of minimum detectable differences (MDD) that can be expected seem only compatible with the monitoring of soil acidification and changes in carbon stocks in the long-term. Future prospects should focus on the improvement of the MDD assessment.

Key Words

Forest soil, natural background mapping, soil monitoring.

Introduction

Soil protection should become a major environmental concern in Europe as the importance of soils in human activities and ecosystem functioning has recently been highlighted by the Soil Thematic Strategy for the Protection of Soil. Soil monitoring networks may be used as instruments (i) for the identification of risk areas according to major soil threats, (ii) for early detection of evolution, and (iii) to evaluate the effectiveness of soil protection measures (Van-Camp *et al.* 2004). The Walloon Forest Inventory is a region-wide programme dedicated to the monitoring of the forest condition in southern Belgium with a density of one observation every 50 ha. 10 000 observation plots are thus distributed over the 530 000 ha of forest land, along a regular 1.0 x 0.5 km rectangular grid. A Forest Soil Survey (FSS) is also being implemented from a selection of one tenth of these points. The monitoring network constitutes therefore the most detailed survey dedicated to assessment of forest soil conditions in southern Belgium. The objective of this paper is to assess the situation at mid-term of the first investigation stage regarding both mapping and monitoring potentialities of the network.

Material and methods

Field work and laboratory analyses

The 10 000 forest observation plots are located at the intersection of a regular 1.0 x 0.5 km grid, of which about ten percent should be soil-monitored. According to situations encountered on the field, 80 to 90 plots are sampled every year, which theoretically supposes a time-frequency of 10 years for monitoring considerations. Up to now, five field campaigns have been completed and 410 soil samples have been analyzed. After field characterization of biophysical environment, soil was sampled by pooling twenty 20 cm-deep cores taken at the perimeter of three concentric circles (3 m, 9 m, and 15 m radius). The organic layers were removed before sampling. The samples were air-dried immediately after sampling and then sieved at 2 mm. A portion was ground to 200 μ m for total analysis. The following variables were measured in the laboratory: total organic carbon (TOC), total nitrogen (NT), pH_{water} , pH_{KCl} , exchangeable acidity (Ac_{EXC}) and aluminium (Al_{EXC}), cationic exchangeable capacity (CEC), NH_4Cl -extractible (EX) cations (Ca, Mg, K, Mn, Fe, Zn), total (T), mineral (MIN), and extractable (EX) P, and aqua-regia extractible (T) concentrations of Ca, Mg, K, Al, Fe, Mn, Cd, Co, Cr, Cu, Ni, Pb, and Zn.

Data processing and statistical methods

Statistical analysis were performed in order to (i) resume the data and identify the presence of possible subsets and outliers within the general population, (ii) identify and organize hierarchy within the driving factors of the soil properties, especially the lithological determinism, (iii) identify sites where risks of unfavourable forest development would need further investigations, and (iv) produce regional maps of the forest condition status. Multivariate Principal Component Analyses (PCA) were performed to summarize information and identify factors driving soil properties. The spatial structures of the variables were studied and compared to the geographical distribution patterns of various natural spatial entities (lithology, soil groups, ecological territories).

In order to predict the level of change that can theoretically be detected between two surveys, the power analysis or derived methods have frequently been used. The power ($1-\beta$) of a test is defined as the probability to reject null hypothesis when it is false. According to Dagnelie (1975), if α and β are small enough, respectively $\leq 0,1$ and $\leq 0,5$, the following relationship may be written:

$$N = \frac{2 * (u_{1-\alpha/2} + u_{1-\beta})^2 * \sigma^2}{\delta^2} \quad (1)$$

where σ^2 is the variance of the population and δ the mean differences, or the Minimum Detectable Difference (MDD) if the other parameters are fixed.

Results

What is the representativeness of the network according to soil spatial variability?

Forested areas represent 530 000 ha out of 1 690 300 but are unevenly distributed across Wallonia, depending on climatic, topographical, and lithological factors. Forest soils are mainly Cambisols, according to WRB classification. The other soil types which can be found under forest are very weakly represented (Luvisols, Regosols, and Gleysols), or even not at all (Podzols). The soils are mainly well drained and stony, as a consequence of both relief and lithology. For synthesis purpose (Figure 1), soil groups were classified according to texture (S: sand; L: loamy-sand; A: silty; E: clay; G: loamy and stony), nature of stones (fi: slate; r: shale and sandstone; f: shale; p: micaceous sandstone; k: limestone), intensity of natural drainage (1: favourable; 2: deficient). Other soils are only differentiated into peat soils, other stone charge, and other soils (complexes and artificial soils). In the FSS, stony soils represent 85% of samples. The nature of the stone charge is dominated (35%) by mixes of shales and sandstones. Unmixed charges of shale or sandstone parent materials are however very frequent too, respectively 26% and 19%. The soil thickness was classified into five classes by slices of 20 cm. Thirty percent of FSS soils are shallow (< 40 cm) while 35% are deep (> 80 cm). Seven classes of humus types have been identified from calcic mull to peat. Most frequent types are moder (35%), mull-moder (30%) and mull (16%). The most discriminating soil morphological properties in the FSS are the nature and abundance of the stone charge, the thickness of loose material, and the humus type.

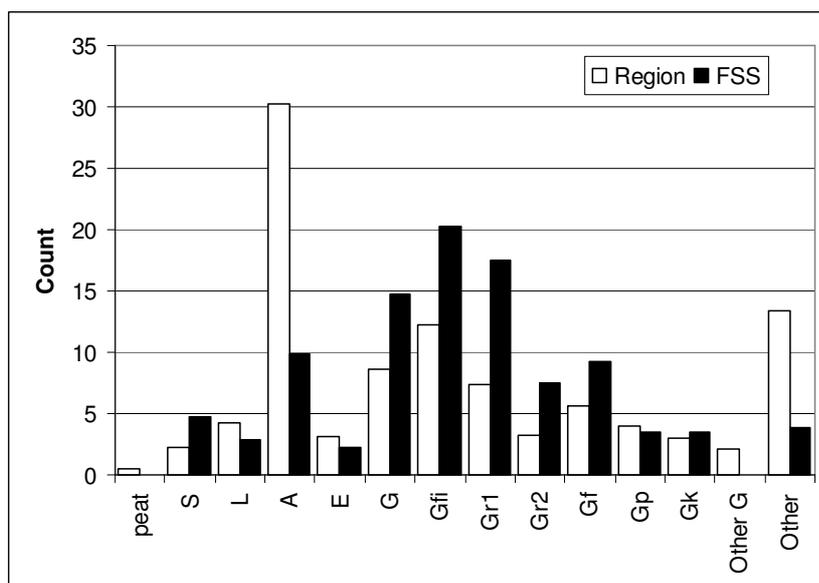


Figure 1. Frequency distribution of main soil groups in Walloon region and in the Forest Soil Survey.

What are driving factors of soil properties

Statistical indicators were calculated for each variable (data not shown). Most distributions are right-tailed skewed, which is common for soil properties (Webster, 2001). Skewness is particularly high for Pb_T (13.45), Cd_T (7.52), Ca_T (6.83), Zn_{EX} (6.65), Mg_{EX} (5.82), P_{MIN} (4.79), P_{EX} (4.53). To the exception of P, asymmetry seems mainly due to the occurrence of soils developed on two contrasted types of lithology, that is the detritic rocks composed basically by quartz on the one hand, and carbonated rocks on the other hand. The classical pedological characteristics (organic status, pH, CEC) present generally less variation than total chemical reserves and particularly than exchangeable pools.

A Principal Components analysis (PCA) was performed on the data in order to visualize the relationships between the variates and to identify the main factors driving their variability in the FSS. Results are presented in Figure 2. The 34 variables analyzed present high correlation coefficients and almost 70% of the variability is taken into account by the first four components of the ACP. The first axis is driven by the variables linked to presence of calcareous material). The second axis is influenced by most of total elements for which the distribution in soils formed on detritic rocks is linked to the abundance of quartz which plays as dilutant phase. The third axis expresses the variations of organic content and CEC which are closely linked. The fourth axis bears variability of P, which appears as an element with very specific behaviour as it can not easily be linked with other soil properties. It should be noticed that the exchangeable elements, especially Zn, are the variable for which the variations are the least taken into account by the four axis mostly because the behaviour of these elements in soil surface are sensitive to various environmental conditions which are specific for each element and hence scatters the weight of exchangeable pools on several different axis.

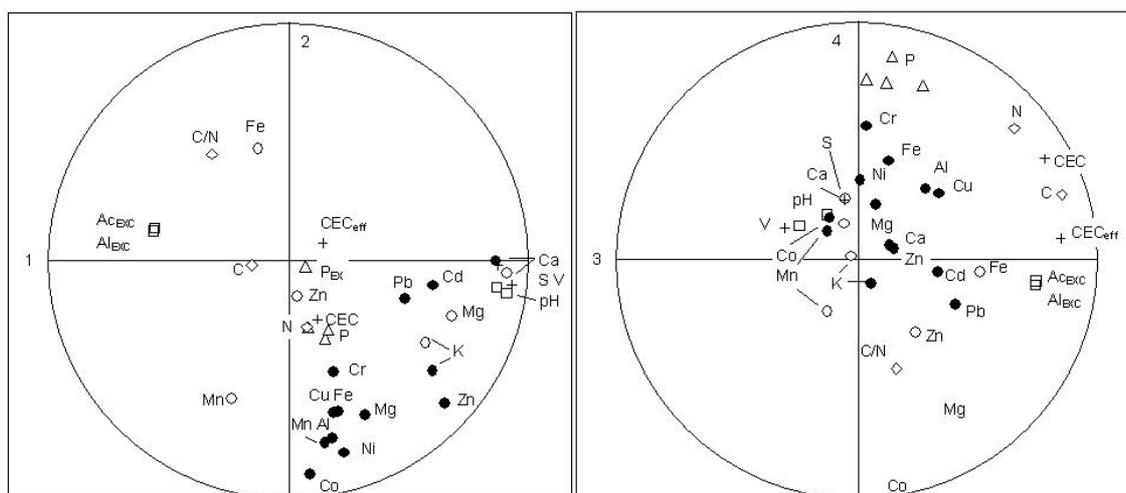


Figure 2. Scatter plots of correlations between forest soil properties and the first two principal components (left) or third and fourth (right). The symbols used for plotting soil variables are: \diamond for organic status, \square for acidity status, $+$ for CEC group, \circ for NH_4Cl extractable elements, \bullet for total elements, and Δ for P forms.

What is the network sensitivity to detect evolution?

MDD have been calculated according to Dagnelie (1975) for every variate (table not shown). The calculations were made considering $\alpha = 0.05$, $\beta = 0.10$, and assuming that 90 samples would be collected each year. The results for untransformed data can be directly linked to the variability found in the distributions. The higher variance, the larger relative confidence interval and MDD. Given the high number of samples, the maximum relative error on the estimation of the mean is between 2 and 5% for variables presenting the lowest variations and can amount to 15-30% for Ca contents. The best measurable differences to expect concern pH, C:N, CEC, exchangeable acidity, and organic content, which are variables that one wouldn't expect to see changing as fast as exchangeable pools of elements. Results for transformed data clearly stress the importance of having distributions approaching normality, even when the size of the sample is large. Calculated MDD appear higher than those found by other authors (Brejda *et al.* 2000; Goidts and van Wesemael 2007) but studies concern different environments and are therefore barely comparable. Moreover, we chose to fix a rather high level of power for the test in order to reduce the risk of missing effective evolutions.

Monitoring soil acidification or changes in carbon stocks within the FSS seems therefore promising. For the other variables, sample can be stratified into subsets with physical meaning, such as lithology or relief. Identifying local trends could be also of more interest than assessment of a trend for regional mean. Provided that their number of samples be high enough, MDD may be calculated for geographical subsets.

What about mapping the soil properties?

At the regional scale, some long-range spatial structures could be identified. These result mainly from the geological structure of the Walloon region, where the lithological zonation is rather clearly marked. A subsequent goal of the stratifications is to allow the regional mapping through the attribution of distinct values to the polygons of existing soil, lithological, or ecological maps. As the number of samples in the various groups is largely unbalanced, non-parametric tests were preferred to parametric and Kruskal-Wallis tests were performed in order to identify groups with different medians (data not shown). Relationships were found between soil properties, mostly the acido-basic status and the variables linked to the nature of the parent material, and main soil types, or ecological territories. The soil map (texture and nature of stone charge) appears relevant at that scale too but does need a generalization process and fails however to differentiate the intra-type soil spatial variability. Some techniques of data interpolation combining qualitative and quantitative informations were investigated (results not shown). The density of observations in FSS allows regional mapping and identification of local specificities.

Conclusion

Forest soils in Wallonia are mainly Cambisols developed from sedimentary rocks. However, some diversity can be found among the soil series within short distances. The first results therefore show a large extreme-based variability and moderate variation coefficients. The exchangeable cations and carbonate-sensitive variates present the highest variabilities. Frequency distributions are often largely skewed. As a result, the prediction of statistical parameters suffers from a lack of precision and most data need transformation to approach normal distributions. Assuming that the variance of the sample was properly known, minimum detectable differences were assessed at regional scale for low levels of α and β error risks, and for annual evaluations. The resulting MDD appear therefore rather high for some variables, especially the exchangeable pools and the total contents, compared to the speed of soil transformations resulting from natural processes. However, smaller MDD should be obtained by (i) allowing to loose test power, (ii) raising the size of the sample through consideration of longer periods (e.g. 4 or 5 years), and (iii) by reducing the variance of the sample. For this particular point, the stratification of the survey according to qualitative attributes seems the most appropriate solution. Stratification constitutes furthermore a way for geographical differentiation of the expected MDD. On the other hand, scattering the sample into homogeneous subsets reduces the size of the comparison set and might lead to a loss of precision for monitoring considerations if the decrease of the variance is not marked enough. Moreover, it shouldn't be forgotten that the bigger the sample the more reliable estimation of the variance (Webster 2001). The sampling intensity of the FSS allowed rather fine geographical differentiation for every variable, which constitutes its main contribution to the knowledge of soil conditions in Wallonia. Sound references for pedo-geochemical content are now available and should allow easier identification of contaminations from both natural and human origins.

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