PROJECT INFORMATION

Project title: Temporal trends in soil solution acidity in European forests

Project ID: 78

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PROJECT DESCRIPTION

Objective(s) of the project:
The data will be used in a cooperative study that aims to clarify the trends in acidity of soil solutions in European forests.

The objectives are to:
- assess soil solution trends of specific acidity indicators (pH, ANC, BC:Al) across Europe at ICP Forests sites;
- evaluate whether the trends are dependent on the type of soil, the initial state of acidification of the soil and the tree species;
- explain the change in acidity indicators by evaluating possible drivers, specially the effect of past deposition of potential acidity and processes controlling the changes.

The research questions are:
- How did acidity indicators change in soil solutions (in different depth classes) during the last 10-20 years?
- Do the changes in those indicators differ between the types of collector (zero-tension lysimeters versus tension-lysimeters)?
- Does the change in those indicators differ within i) soil buffer systems (acid, gradient from acid to neutral pH, calcareous soils), in different classes of ii) cation-exchange capacity, (iii) base saturation (BS) and for iv) different tree species?
- Does the change in those indicators differ depending on the gradient in soil acidity (pH, BS) with depth?
- What is the role of soil sulphur (S) desorption in retarding the recovery of soil solution acidification?
- Do the changes in soil solution acidity reflect the changes in soil acidity parameters (pH, BS) between both soil surveys? Are they driven by changes in deposition (potential acidity, nitrogen (N), S)?

The hypotheses are:

- Soil solution acidification, measured by pH, ANC, BC:Al ratio and total aluminium (Al) concentration, markedly slows down during the last 10-20 years, especially in the upper mineral soil (0-40 cm).
- The reduction in acidification rate is more marked in acid soils but not visible in soil with moderate pH and BS values.
- The reduction in acidification rate is correlated with the reduction in acidifying deposition.
- Acidification rates decrease more markedly in soils under broadleaved vegetation than in soils under conifer vegetation.

Scientific background of the project:
Atmospheric deposition of N and S to terrestrial ecosystems leads to eutrophication and acidification. During the years from 1960 to 1985 a fast acidification of soils and waters (surface and drainage) was experienced in reaction to acid atmospheric deposition.

At increased acid loads, pH in soil declines. Base cations (BC) adsorbed to the ion exchange complex can be exchanged with acidic cations and possibly lost by leaching. The soil is gradually depleted in BC, mainly divalent cations like calcium (Ca^{2+}) and magnesium (Mg^{2+}). At low pH and high acidification, Al dissolves and tends to form toxic species. A larger fraction of exchange sites will become occupied by Al at the expense of sites occupied by Ca^{2+} and Mg^{2+}. Elevated Al concentration in the soil solution may damage fine roots and mycorrhizae and thus reduce nutrient and water uptake (Foy 1988; Ulrich 1983; Boudot et al. 1994). Aluminium might also cause reduced root growth (Godbold and Hüttermann 1988; Godbold and Kettner 1991; Godbold et al. 1988). The soil solution molar ratio between BC (BC=Ca+Mg+K) and Al has been suggested as a chemical criterion for forest condition in critical loads calculations for forest ecosystems (Sverdrup and Warfwinge 1993). The simpler molar ratio between Ca and Al has also been suggested (Cronan and Grigal 1995; Ulrich 1981).

The emission of S and the deposition mainly in the form of S-sulphate have both decreased significantly during the last 20 years. The emission of N compounds shows tendency to decrease while the deposition of N at some places in Europe decrease while it at other places increase. However, a total reduction in deposition is apparent and it has raised questions about the recovery of waters and soils from former acidification.

Several studies investigating the temporal changes in soil solution acidity over the past decades at regional or national scale have recently been published (Akselsson et al. 2013; Benham et al. 2012; Brumme et al. 2009; Graf Pannatier et al. 2011; Löfgren and Zetterberg 2011; Vanguelova et al. 2010; Verstraeten et al. 2012) They show that soil solution has reacted differently to atmospheric pollution and that other factors (e.g. sea-salt episodes) have changed their composition for more or less long periods.

A statistical comparison of the two soil surveys conducted in the 1990s and 10 years later in ICP Forests showed that the pH increased in the acid forest soils (pHCaCl2 < 4.0) but further decreased in forest soils with pH (CaCl2) above 4.0. Similar to the trend in pH, BS increased in soils with a low BS (<20%) but decreased in forest soils with BS above 20% (Cools and de Vos 2010). This is in line with the hypothesis of Blaser et al. (2008) who proposed a method to assess the sensitivity of forest soils to acidification. They suggested that the risk for a decrease in BS was higher in soils with pH between 3.6 and 5.5 and a BS between 10% and 95%. The question whether the long-term observation of soil solution composition would reflect the changes in soil chemistry is still unresolved. Matschonat and Vogt (1998) suggested that due to the decreasing ionic strength in the soil solution, the already low BS of certain European soils may even decrease. However, the fraction of Al in soil solution should decrease compared to the BC, resulting in increasing BC:Al ratio. This would lower the toxicity risks for plants but decrease the pool of available cation nutrients.

Needed ICP Forests data and analyses
The trend analyses will be carried out using the aggregated soil solution dataset of ICP Forests or a draft version of this aggregated set. We plan to explore any temporal trends in soil solution indicators for acidification. As indicators we have chosen BC, Al, BC:Al followed by pH and ANC where available. Additional variables such as NO_3^- SO_4^{2-} concentration, where available, would be included in our analysis. In a first step, changes in soil solution acidity will be related to the acidity status of the soil profile. A classification scheme (Kölling et al. 1996; von Wilpert et al.1996) will be used to characterize the acidity gradient in the soil profile. Changes in soil solution acidity will be related to changes in deposition (potential acidity, N, S). Different levels of deposition might be used. In a second step, the changes in soil solution will be related to changes in soil acidity parameters (pH, BS) between two soil surveys and to those in deposition of N, S and potential acidity. Data for soil solution, soil and deposition are therefore needed.
Monotonic trends will be detected based on the Mann-Kendall test at plot level, while linear mixed models will be used to analyze linear temporal trends for groups of plots (all together or classified according to site factors). A generalized additive mixed model (GAMM) might be used for trend analysis in non-monotonic data. Trend analysis should be carried out on as long time series as possible available at a site. The slope (change per year) will be compared between sites.

Publications of results
It is the intention to write one joint publication with ICP Forests experts from participating countries (in accordance with the ICP Forests Intellectual Property Policy).

References

- Akselsson, C., H. Hultberg, P. E. Karlsson, G. Pihl Karlsson and S. Hellsten (2013). "Acidification trends in south Swedish forest soils 1986-2008 - slow recovery and high sensitivity to sea-salt episodes." Sci Total Environ 444: 271-287.
- Benham, S. E., E. I. Vanguelova and R. M. Pitman (2012). "Short and long term changes in carbon, nitrogen and acidity in the forest soils under oak at the Alice Holt Environmental Change Network site." Science of The Total Environment 421–422(0): 82- 93.
- Blaser, P., L. Walthert and E. Graf Pannatier (2008). "The sensitivity of Swiss forest soils to acidification and the risk of aluminum toxicity." Journal of Plant Nutrition and Soil Science 171(4): 605-612.
- Boudot, J. P., Becquer, T., Merlet, D., & Rouiller, J. (1994). Aluminum toxicity in declining forests: A general overview with a seasonal assessment in a silver fir forest in theVosges mountains (France). Annales des Sciences Forestières, 51, 27–51.
- Brumme, R., H. Meesenburg, M. Bredemeier, C. Jacobsen, E. Schönfelder, K. J. Meiwes and J. Eichhorn (2009). "Changes in Soil Solution Chemistry, Seepage Losses, and Input–Output Budgets at Three Beech Forests in Response to Atmospheric Depositions." 208: 303-336.
- Cools, N. and B. De Vos (2011). "Availability and evaluation of European forest soil monitoring data in the study on the effects of air pollution on forests." iForest - Biogeosciences and Forestry 4(5): 205-211.
- Cronan, C. S., & Grigal, D. F. (1995). Use of calcium/aluminium ratios as indicators of stress in forest ecosystems. Journal of Environmental Quality, 24, 209–226.
- Foy, C. D. (1988). Plant adaptation to acid, aluminium-toxic soils. Communications in Soil Science and Plant Analysis, 19, 959–987.
- Godbold, D. L., & Hüttermann, A. (1988). Aluminium toxicity and forest decline. Proceedings of the National Academy of Sciences of the United States of America, 85, 3888–3892.
- Godbold, D. L., & Kettner, C. (1991). Use of root length elongation studies to determine aluminium and lead toxicity in Picea abies seedlings. Journal of Plant Physiology, 138, 231–235.
- Godbold, D. L., Dictus, K., & Hüttermann, A. (1988). Influence of aluminum and nitrate on root growth and mineral nutrition of Norway spruce (Picea abies) seedlings. Canadian Journal of Forest Research, 18, 1167–1171.
- Graf Pannatier, E, A. Thimonier, M. Schmitt, L. Walthert and P. Waldner (2011). "A decade of monitoring at Swiss Long-Term Forest Ecosystem Research (LWF) sites: can we observe trends in atmospheric acid deposition and in soil solution acidity?" Environ Monit Assess 174(1-4): 3-30.
- Kölling, C., Hoffmann, M. Gulder, H.-J. 1996. Bodenchemische Vertikalgradienten als charakteristische Zustandsgrößen von Waldökosystemen Zeitschrift für Pflanzenernährung und Bodenkunde 159, 69–77
- Lofgren, S. and T. Zetterberg (2011). "Decreased DOC concentrations in soil water in forested areas in southern Sweden during 1987-2008." Sci Total Environ 409(10): 1916-1926.

- Matschonat, G. and R. Vogt (1998). "Significance of the total cation concentration in acid forest soils for the solution composition and the saturation of exchange sites." Geoderma 84(4): 289-307.
- Sverdrup, H., & Warfwinge, P. (1993). The effect of soil acidification on the growth of trees, grass and herbs as expressed by the (Ca+Mg+K)/Al ratio. Lund University, Department of Chemical Engineering II, Report 2 :1993, ISSN 1104-2877, KF-Sigma, Lund, 177 pp.
- Ulrich, B. (1981). Eine ökosystemare hypothese über die ursachen des tannensterbens (Abies alba Mill.). Forstwissenschaftliches Centralblatt, 100, 228–236.
- Ulrich, B. (1983). An ecosystem oriented hypothesis on the effect of air pollution on forest ecosystems. In G. Persson, & A. Jernelöv (Eds.), Ecological effects of acid deposition (pp. 221–231). Stockholm: Swedish Environmental Protection Board, SNV-PM 1636.
- Vanguelova, E. I., S. Benham, R. Pitman, A. J. Moffat, M. Broadmeadow, T. Nisbet, D. Durrant, N. Barsoum, M. Wilkinson, F. Bochereau, T. Hutchings, S. Broadmeadow, P. Crow, P. Taylor and T. Durrant Houston (2010). "Chemical fluxes in time through forest ecosystems in the UK - soil response to pollution recovery." Environ Pollut 158(5): 1857-1869.
- Verstraeten, A., J. Neirynck, G. Genouw, N. Cools, P. Roskams and M. Hens (2012). "Impact of declining atmospheric deposition on forest soil solution chemistry in Flanders, Belgium." Atmospheric Environment 62: 50-63.
- Von Wilpert, K. 1996. Aus der BZE abgeleitete Indizien einer bodenchemischen Drift in Baden-Württemberg. Mitt. Dtsch. Bodenkdl. Ges. 79, 189-192.