Spatiotemporal variability in soil acidity, the role of micro topography and plant-soil interactions in wet meadow habitats

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Problem description

Numerous studies exist in which field measurements are used to define relationships between soil characteristics and vegetation. The statistical strength and the general applicability of these relationships are, however, highly dependent on spatiotemporal heterogeneity of the soil and thus on sampling strategy. We demonstrate the importance of spatiotemporal variability, as well as of sound ecological knowledge, by considering relationships between soil acidity (pH) and plant response to acidity (R_m).

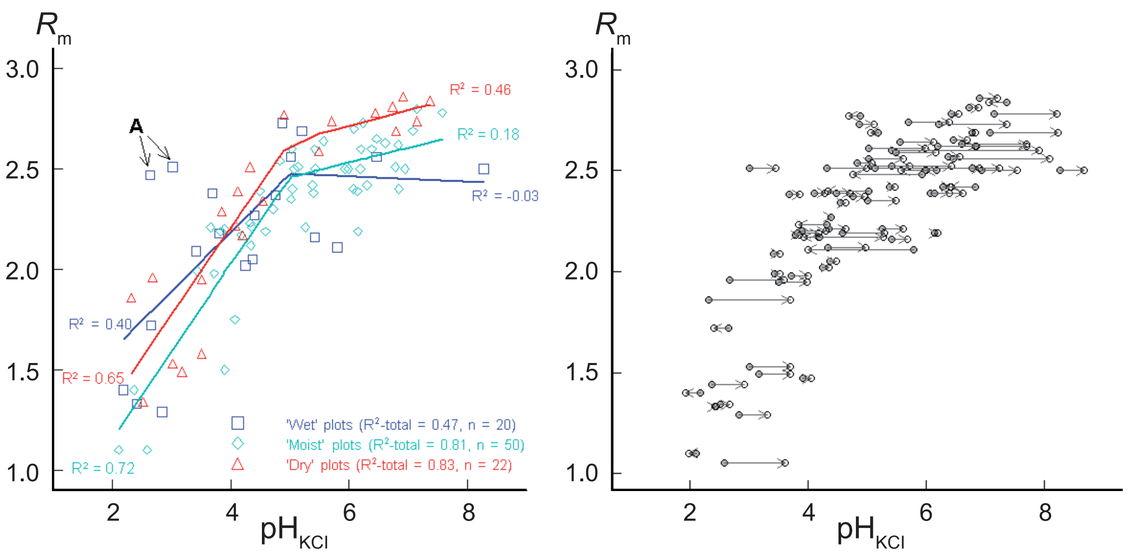

Fig. 1. pH_{KCl} vs R_m and fitted segmented regression models for 'wet', 'moist' and 'dry' plots. Coefficients of determination, R^2, are given for the segments and total regressions.

Fig. 2. pH_{KCl} measurements taken at 0-5 (grey dots) and 5-25 cm (open dots) below surface level at the same location per plot.

Relating soil acidity to plant response

The shape of the pH-R_m relationship (Fig. 1) is mainly governed by Al toxicity. This is reflected in the breakpoint at pH 5.0, above which Al^{3+} in soil solution is below toxic values and pH-controlled deficiencies of elements crucial for plant growth (like P, Fe and Zn) slowly become more important. The strength of the relationship declines with increasing wetness of the plots (Fig. 1). 'Wet' plots show a significantly lower correlation and hence they contribute substantially to the noise in the overall relationship. Explanations for this are:

1. Upward flow of alkaline groundwater in combination with micro topography results in large spatiotemporal heterogeneity within plots
2. Species adapted to reduced soil conditions can adjust rhizospehere acidity by leaking oxygen to the soil.

The ability to influence rhizosphere acidity makes aerenchyma containing species relatively indifferent for differences in soil pH above approximately pH 5, providing an explanation for the breakdown of the pH-R_m relation for wet sites in Fig. 6.

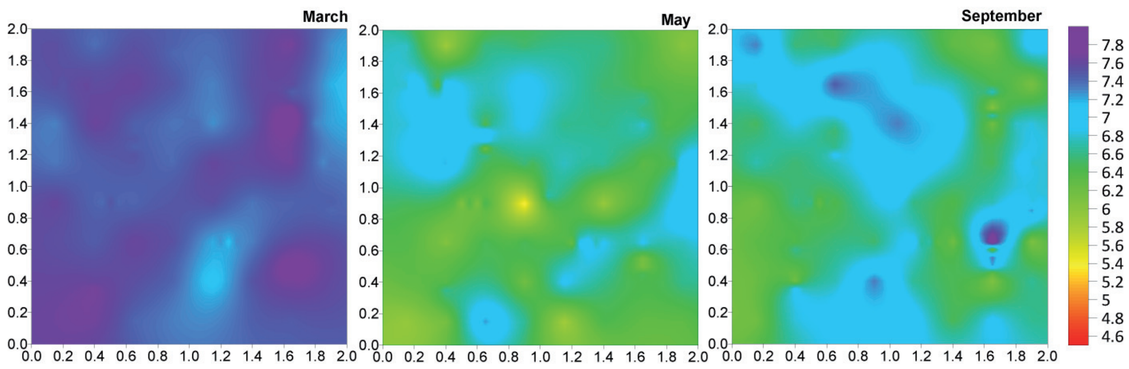

Fig. 3. Spatiotemporal variation of in situ measured pH, of an intensively measured plot of 2x2 m (measurement interval: 25 cm).

*Fig. 4. Micro topography measured on a grid of 5 * 10 cm. (Correlation range 1 m, relief 0.11 m, random roughness 1.9 cm)*

Micro topography and upward seepage

The combination of micro topographical variation and a shallow groundwater table results in saturation excess overland flow at micro scale depressions, while on hummocks infiltration of precipitation water can still continue (Fig. 5). This process results in micro scale gradients from relatively alkaline hollows to more acidic hummocks. Moreover hollows will experience longer periods of inundation, and consequently longer periods with low redox potential, which are accompanied by consumption of H^+ and production of HCO_{3^-}. Geostatistical analysis of detailed pH data (measurement interval of 20 cm) indicates that a large part of pH variation occurs at very small scales, suggesting influence of roots.

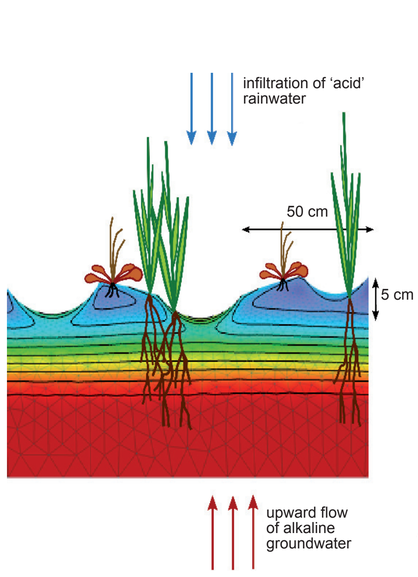

Fig. 5. Influence of micro topography and upward seepage on spatial variation in water quality

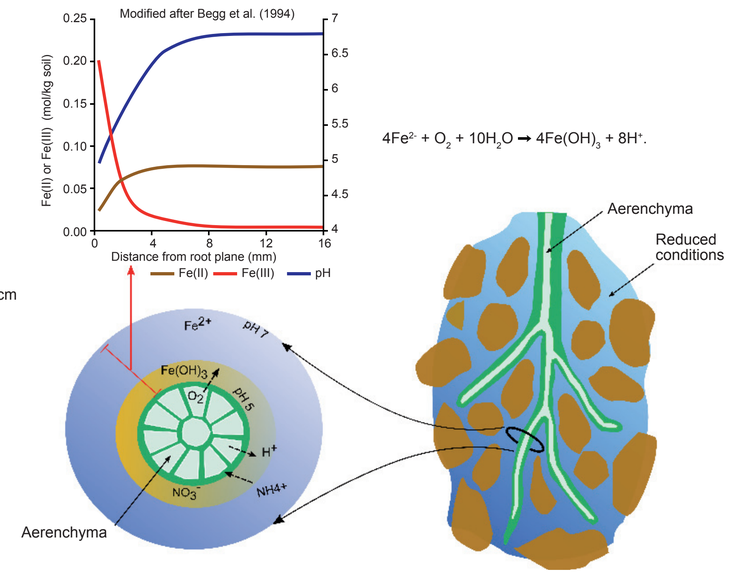

Fig. 6. Rhizosphere acidification by species containing aerenchyma in reduced soils. Diffusion of oxygen from the root tissue results in iron oxidation an consequently in a drop of pH close to the root surface.

Conclusions

- **Insight into the response of plant species to variation in environmental conditions is crucial to assess robust relationships, i.e. relationships that are applicable to no-analogue conditions.**
- **Relationships between soil-acidity and plant response are strongly influenced by the moisture status of the soil.**
- **To avoid systematic errors and statistical noise, ecologists should agree upon a systematic sampling strategy of soil acidity (i.e. same depth, time and instrument for each plot).**

Reference: Cirkel, D.G., Witte, J.P.M. & van der Zee, S.E.A.T.M. (2010) *Towards improved relationships between soil acidity and vegetation: incorporating mechanistic understanding and spatiotemporal variability*; submitted to Journal of Ecology.

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