Coupling root dynamics with reactive transport processes in soil-method and example application to phosphorus acquisition from a mineral source in alkaline soils

Frédéric Gérard, Céline Blitz, Philippe Hinsinger, Loïc Pagès

Coupling root dynamics with reactive transport processes in soil

Method and example application to phosphorus acquisition from a mineral source

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Introduction

Numerical models that couple root systems and related functions with soil processes are limited with respect to the description of reactive transport processes in soil, particularly with respect to soil chemistry. For example, aqueous speciation is not taken into account (e.g. Dunbabin et al., 2013). This lack precludes with a comprehensive modelling of soil chemistry using chemical thermodynamic and kinetic principles (e.g. law of mass action, chemical affinity).

Our objectives were two-fold (Gérard et al., 2016):

(1) To develop a soil-plant model that comprehensively describe geochemical processes.

(2) To illustrate its relevance for studying soil-plant interactions. We investigated for illustration purposes the problem of P acquisition from a mineral P source as mediated by nutrient uptake and pH changes in the rhizosphere. This is an important ecological process for the sustainable intensification of agro-ecosystems (e.g. Richardson et al. 2011).

Methods

Model Min3P-ArchiSimple

The root system model
ArchiSimple (Pagès et al., 2014)

Macroscopic approach - Root segments converted into a root surface density in each grid block.

Sequential coupling + data exchange at a daily time step

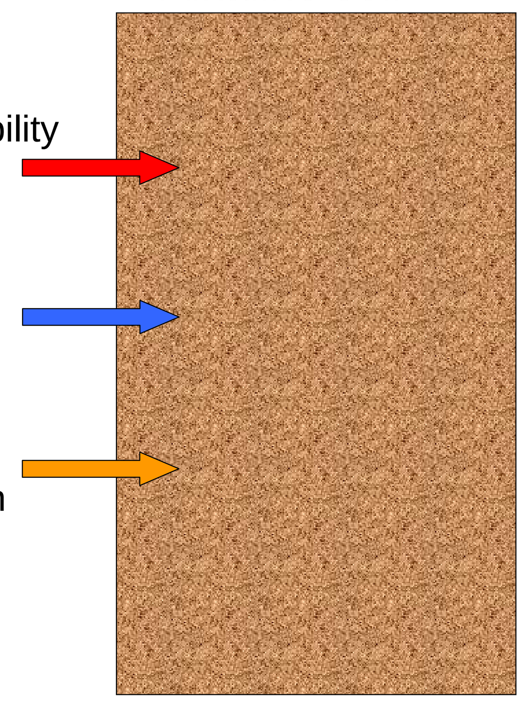
The reactive transport model
Min3P (e.g. Mayer et al., 2012)

Modelling conditions

Growth of a typical root system for monocots

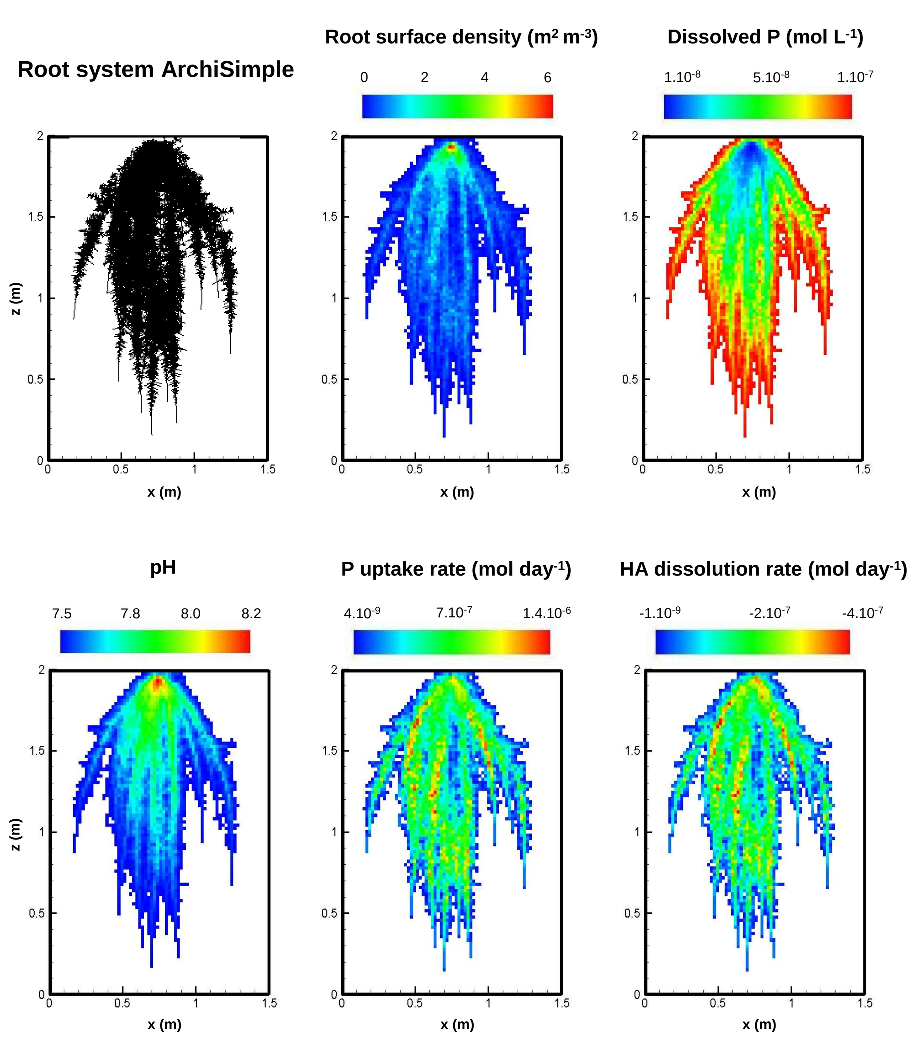
+

Alkaline soil

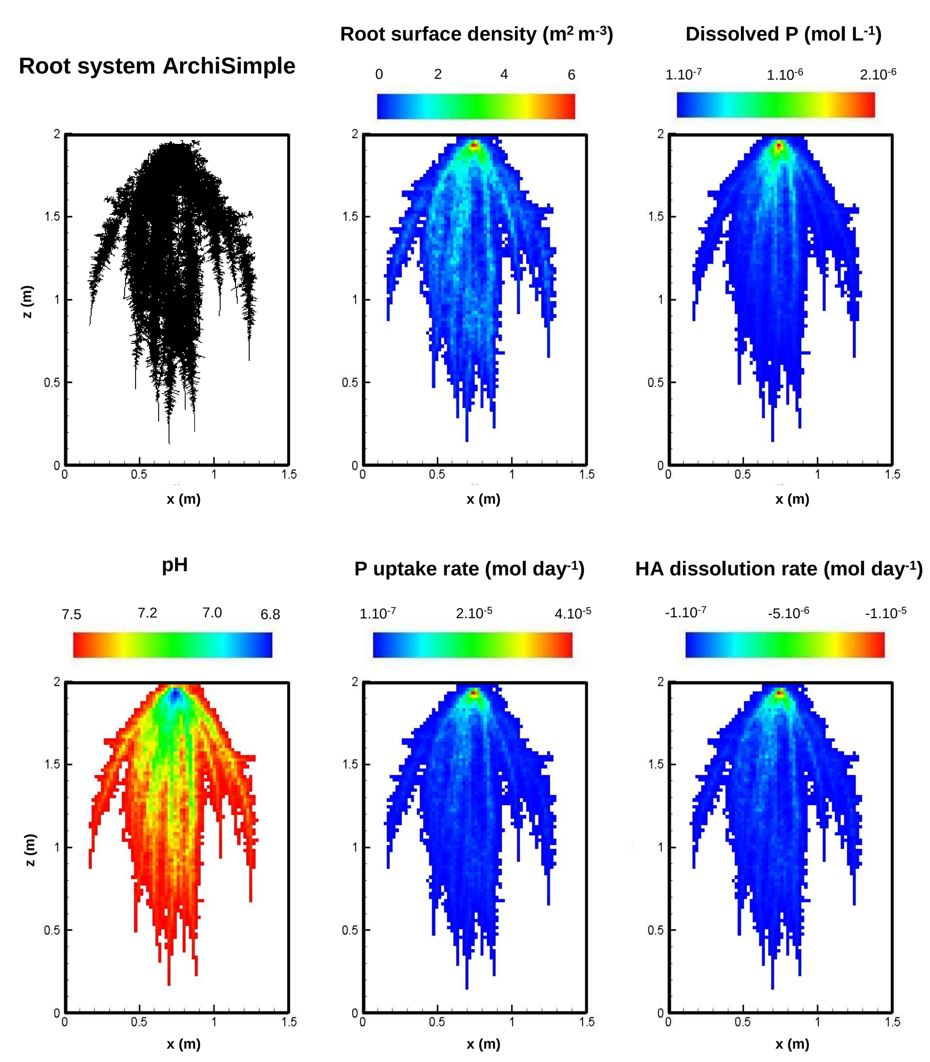


Results

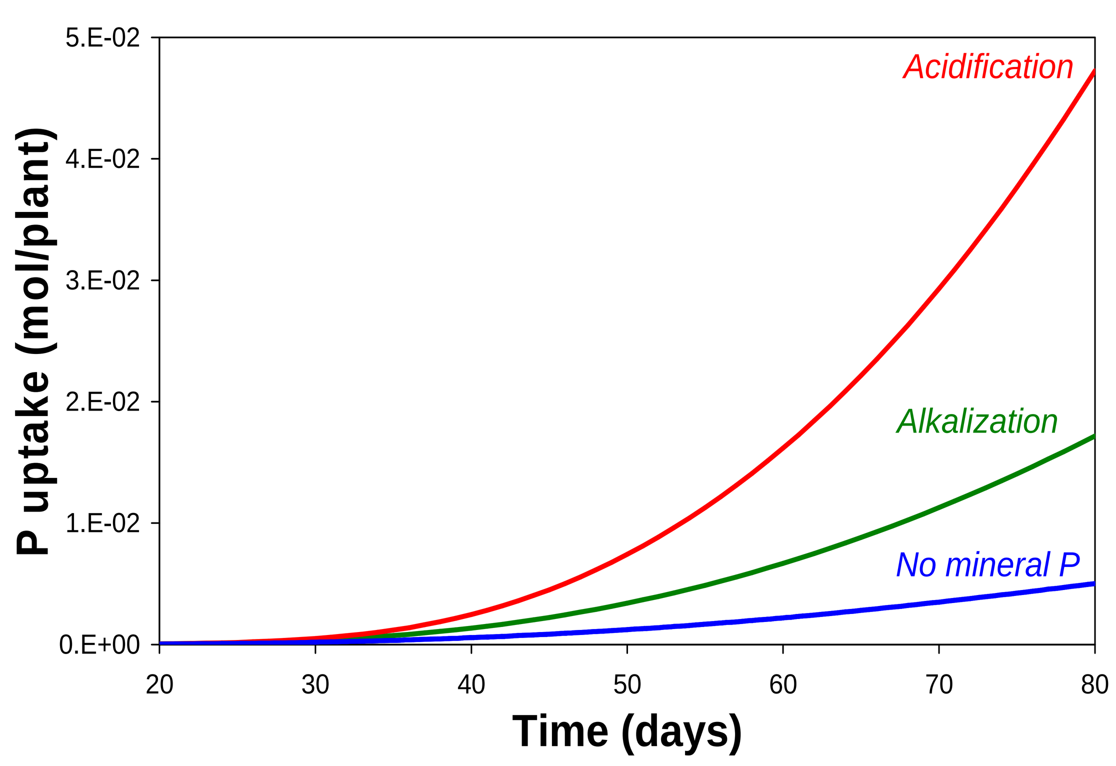
Root-induced alkalization



Root-induced acidification



P uptake whole plant over time



Conclusions

We developed an innovative soil-root system model that comprehensively describes chemical processes (reaction thermodynamics and kinetics) coupled with mass transport processes.

The present application showed that most of the plant P can be issued from hydroxyapatite when root-induced alkalization occurs, thanks to the influence of Ca and P uptake, and confirmed that acidification is much more efficient.

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References

•Dunbabin V M, Postma J A, Schnepf A, Pages L, Javaux M, Wu L H, Leitner D, Chen Y L, Rengel Z and Diggle A J 2013 Modelling root-soil interactions using three-dimensional models of root growth, architecture and function. Plant and Soil 372, 93-124.
•Gérard F, Blitz C, Hinsinger P and Pagès L 2016 Modelling the interactions between root system architecture, root functions and reactive transport processes in soil. Plant & Soil Submitted.
•Mayer K U, Amos R T, Molins S and Gérard F 2012 Reactive transport modeling in variably saturated media with MIN3P: Basic model formulation and model enhancements. *In* Groundwater reactive transport models, Eds F Zhang, G T Yeh, J C Parker and X Shi. pp 187-212. Bentham Science Publishers Ltd.
•Pagès L, Becel C, Boukcim H, Moreau D, Nguyen C and Voisin A S 2014 Calibration and evaluation of ArchiSimple, a simple model of root system architecture. Ecological Modelling 290, 76-84.
•Richardson A E, Lynch J P, Ryan P R, Delhaize E, Smith F A, Smith S E, Harvey P R, Ryan M H, Veneklaas E J, Lambers H, Oberson A, Culvenor R A and Simpson R J 2011 Plant and microbial strategies to improve the phosphorus efficiency of agriculture. Plant and Soil 349, 121-156.