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Modeling the root system of maize to predict water and phosphorus uptake

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ABSTRACT

Our aim was to develop a model for the dynamic simulation of root morphology and architecture. The model intended to support the identification of root traits maximizing the capture of resources from soil. The effects of mechanical constraints in the soil were implemented as well as the distribution, availability, uptake characteristics and dynamics of water and phosphorus. Maize was used as a model crop and the implemented model was tested using contrasting maize genotypes. The model predicted the response of root growth to mechanical soil constraints and the uptake of phosphorus reliably. We are currently testing and improving the model for water uptake.

INTRODUCTION

To ensure food supply of an increasing world population, the yield of new varieties has to keep pace with the demand. To achieve this aim, so called traits-based approaches are becoming more and more important, besides a direct selection for yield. Root architecture is an important target trait for the selection of cultivars, since it determines the efficiency for nutrient and water uptake of a plant. Change in root architecture affect the plant’s access to resources like phosphorus and water. For example, phosphorus may be abundant in superficial soil layers while water in these layers may be depleted during drought periods and only available deeper in the soil. There is some evidence that rooting depth in maize has increased by selection for yield under higher plant densities (Hammer et al. 2009) and under drought stress (Hund et al. 2009). However, in order to optimize root architecture it is necessary to understand its interaction with the spatial and temporal variation of resources in the soil. We aimed to develop a model framework to test and optimize root architecture for resource acquisition depending on the edaphic environment.

METHODS

The developed software implements two independent modules: i) a root module simulating root architecture and dynamics and ii) a soil module simulating resource distribution in soil and mechanical constraints. The root module simulates root architecture and dynamics following the topology of the branching process of the maize root system. The root system is constructed of axile roots and their branch roots, each with specific growth rates, growth orientations and branching ability. The soil model aims to predict the temporal and spatial (two dimensional) variation of H_2O and P as a function of the resource uptake by the root. To model the flow of water in different soils, the Richards equation was solved using a flux updating iterative conjugate gradient algorithm. The uptake of phosphorus on the other hand was simulated using Michaelis-Menten kinetics. Additionally, mechanical constraints can be varied to simulate the effect of differences in soil density, e.g. plow pans, on root growth. Two contrasting genotypes were simulated: a deep rooting modern tropical genotype (CML444; Figure 1) and a shallow rooting model genotype with an increased gravitropic setpoint angle (GSA) (the deviation from vertical 0°) of its axile roots, and an increased final length and number of first and second order lateral roots. Using these contrasting genotypes we aimed to simulate the potential variability of root architecture in maize. The roots growth was simulated in loamy fine sand with the majority of P distributed in the upper 20 cm of the profile. During the period of the simulation (28 days), the plants had to rely on stored soil water.

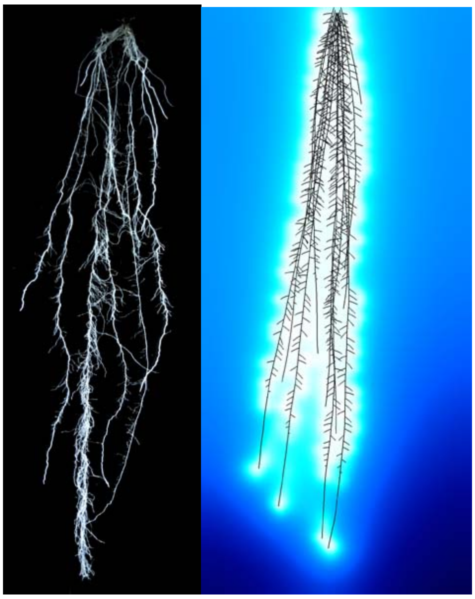

Figure 1. Root system of deep rooted CML444 at 6 fully developed leaves (left) and after 28 days of simulated growth (right).

RESULTS AND DISCUSSION

As a result of the larger GSA and the increased number of lateral roots, the shallow rooted genotype took up about 6 times more P per unit root mass compared to the deep rooted genotype. By contrast, CML444 took up more water due to its greater rooting depth. Currently, the model disregards the effect of water availability on P-uptake which is anticipated to decrease in drying soil. However, the current model is a first step on the avenue towards linking root architecture with resource uptake and soil physical processes. Our further aim is to allow for interactions between nutrient uptake and water availability as well as to implement carbon costs as a factor.

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