Development of a functional-structural root model for pearl millet using OpenSimRoot

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Introduction

Pearl millet is a major source of nutrients in the world's drylands. Despite its tolerance to drought and low soil fertility, its yield remains low and is affected by climate change. The objective of our work is to contribute to the identification of root traits that could be targeted to breed new pearl millet varieties that are more productive and resilient to abiotic stresses. Exploring the impact of root traits in various environments is experimentally difficult.

Using *in silico* models can help explore a large space of parameters to reduce the amount of potential targeted traits to be analysed experimentally. We developed a functional-structural plant model for pearl millet root system using OpenSimRoot (OSR). It combines a model for root system development with a 3D soil model and can be used to analyse the impact of root traits in different soil and climatic scenarios.

Materials and methods

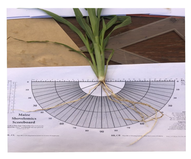
Data collection from the literature

Growth rate for 3 types of lateral root of pearl millet
Climatic and soil data for Bambey (Senegal)

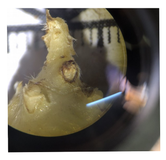
Experimental calibration (cv. Souna 3)

Root growth rate

Number of roots and nodes

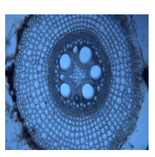


Root branching angle



Distance between nodes

Root hair

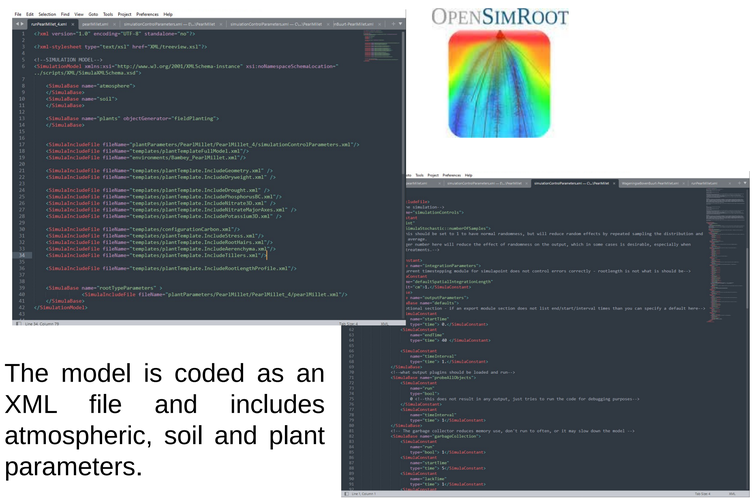


Root anatomy

Leaf area

Photosynthesis

Model implementation within the OpenSimRoot framework



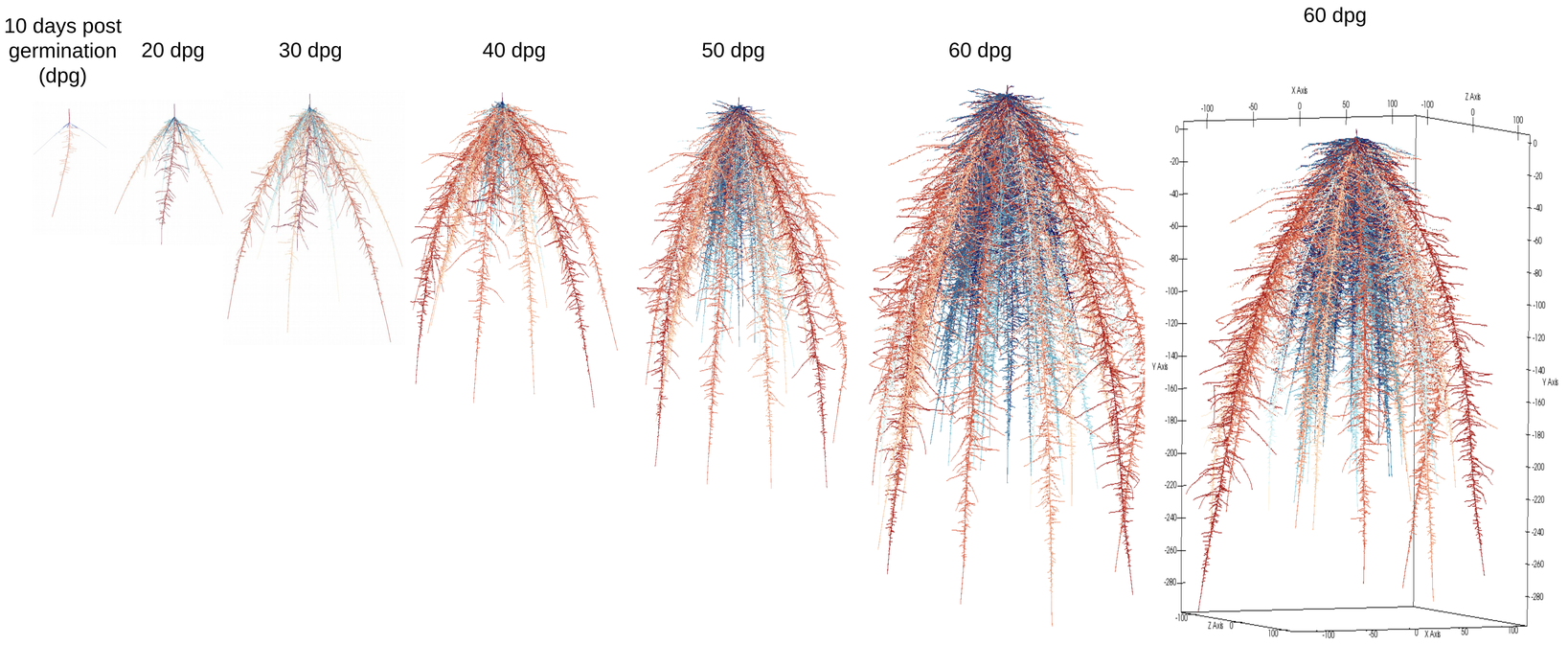
The model is coded as an XML file and includes atmospheric, soil and plant parameters.

Validation data from phenotyping of pearl millet root system in soil

Observations of pearl millet root system in soil profiles at 30cm and 10cm from the plant using a 5 x 5 cm grid.

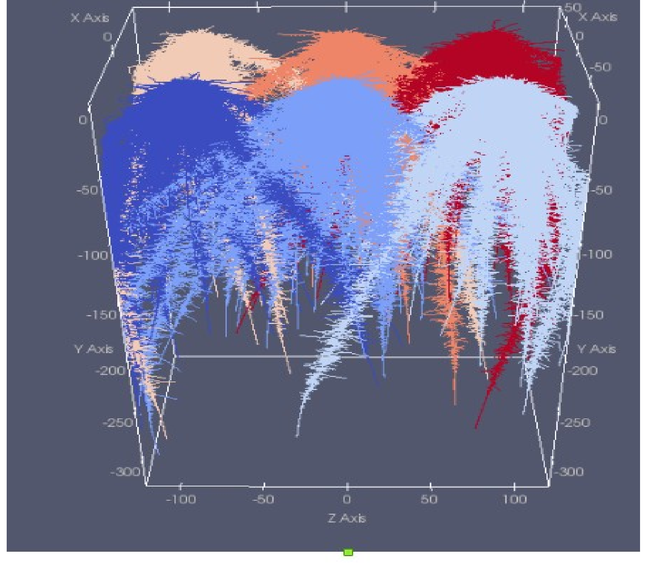
Results

Dynamical 3D model of pearl millet root system development in soil



Growth dynamics of the root system of a pearl millet plant simulated for 60 days in a typical sub-Saharan soil and climate (Bambey)

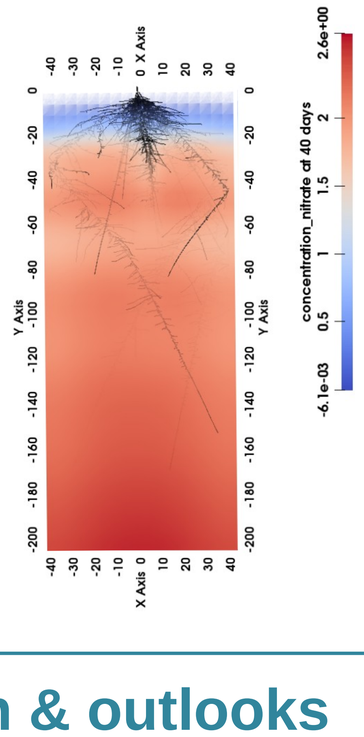
Simulation of plant growth in field condition



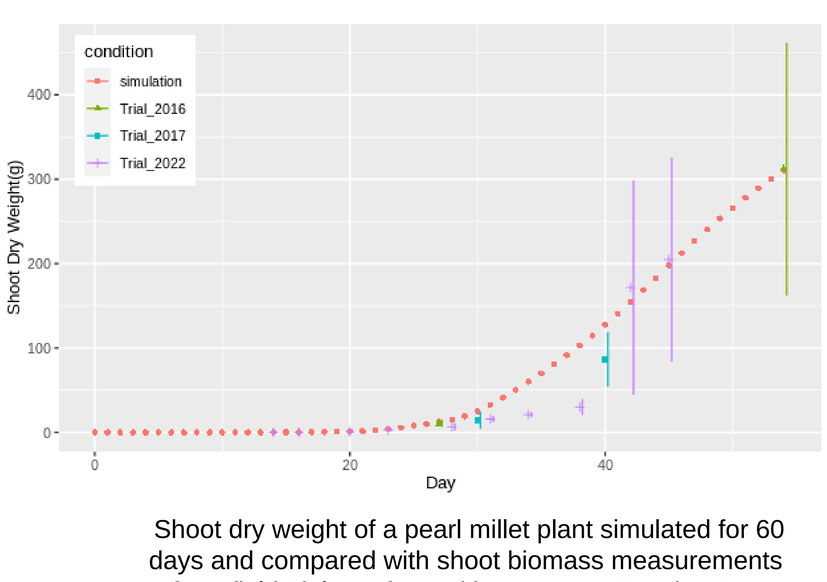
Root system of six pearl millet plants simulated for 60 days under typical field planting density.

Simulation of nutrient acquisition in soil

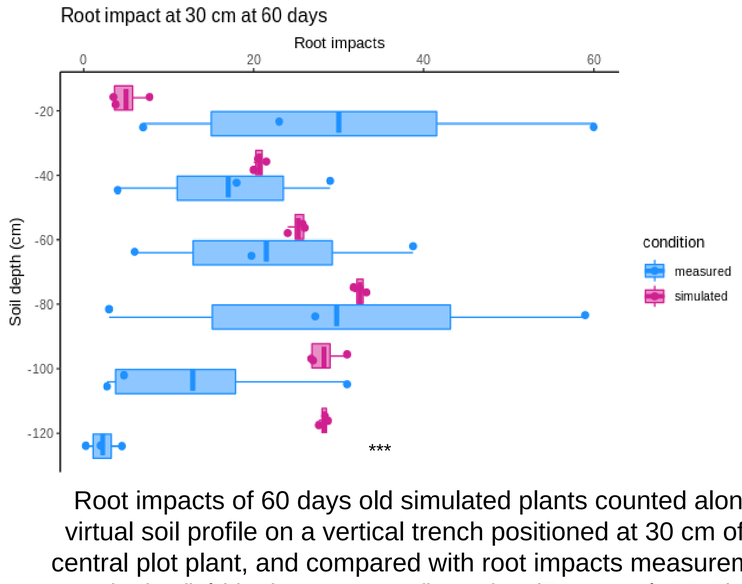
The model has a nutrient module to simulate the simultaneous uptake of solutes, originally implemented to simulate the impact of root system architecture on nutrient uptake, and to test trade-offs for nutrient acquisition



Model validation



Shoot dry weight of a pearl millet plant simulated for 60 days and compared with shoot biomass measurements from field trials performed in 2016, 2017 and 2022.



Root impacts of 60 days old simulated plants counted along a virtual soil profile on a vertical trench positioned at 30 cm of the central plot plant, and compared with root impacts measurements in the field in the same configuration (Faye et al. 2019).

Conclusion & outlooks

Simulations in a typical sub-Saharan soil suggest that the model is able to accurately simulate pearl millet aerial biomass, root growth and function. We will next use the model to test the impact of root architectural and anatomical traits on pearl millet hydromineral nutrition and performance under a variety of stresses.

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