Better modeling of root-soil interactions by explicit representation of soil hardness

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November 16, 2022

Abstract

The vertical distribution of plant roots in the soil profile is a key trait modulating plant contributions to soil carbon storage, drought and nutrient stress resistance, yield, and fitness. However, direct sampling of deep roots requires massive effort, so existing data are sparse and many researchers have adopted modeling approaches to fill data gaps and generate hypotheses about how soil properties change the biogeochemical, agricultural, ecological, and hydrologic consequences of root depth. Such models are useful only if they correctly represent the processes of interest and give accurate predictions of the root systems they simulate. Most current root growth models represent soil as a uniform and unrestrictive medium. This is often a reasonable simplification when modeling roots grown in pots or artificial media, but is less so for field soils which often increase in density, hardness, and heterogeneity with depth. To better predict the effect of soil hardness on root distribution, we updated the structural-functional root growth model OpenSimRoot to explicitly predict soil hardness from soil bulk density, water content, porosity, and depth. Root growth impedance is curently represented by linear scaling of the root elongation rate according to soil hardness. Future work will incorporate configurable growth responses and allow hardness to control changes in root diameter and growth direction, thus allowing the model to examine the fitness implications of carbon reallocation in complex structured soils. Our updated OpenSimRoot captured >50% of observed variation in penetrometer resistance from field soils. When we incorporated soil hardness into simulations of maize growth, we observed a substantial reduction in the predicted root:shoot ratio that overwhelmed previous model predictions of increased water uptake from steeper root angles. These findings reinforce that models considering costs and benefits of deep rooting should routinely consider soil hardess.

Better modeling of root-soil interactions by explicit representation of soil hardness

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Context

- Deeper-rooted crops may ease soil carbon debt while enhancing drought tolerance and N use efficiency. Testing this requires that we observe a lot of roots.
- Roots are hard to observe, so it is useful to stretch our datapoints as far as possible using models. This only works if the model structure is realistic for the question we're asking!
- Most root growth models ignore soil structure and assume growth in a uniform, nonrestrictive medium.
- That's fine when parameterizing from pot experiments, but **ignoring soil structure limits our inferences when modeling field experiments.**

Soil penetration resistance

Gao et al. 2016, Soil & Tillage Res

$$Q = \rho\left(A^{*}\frac{(F-e)^{2}}{1+e}\left(\sigma_{s}{}^{p}-\psi S^{*}\right)^{f}\right)^{2}$$

Where

ρ = soil bulk density, measured

e = porosity, measured or calculate from bulk

σ = net stress, calculated from weight of overlying soil layers:

$$\sigma_i = \sum_{k=0}^{i-1} \rho_k$$

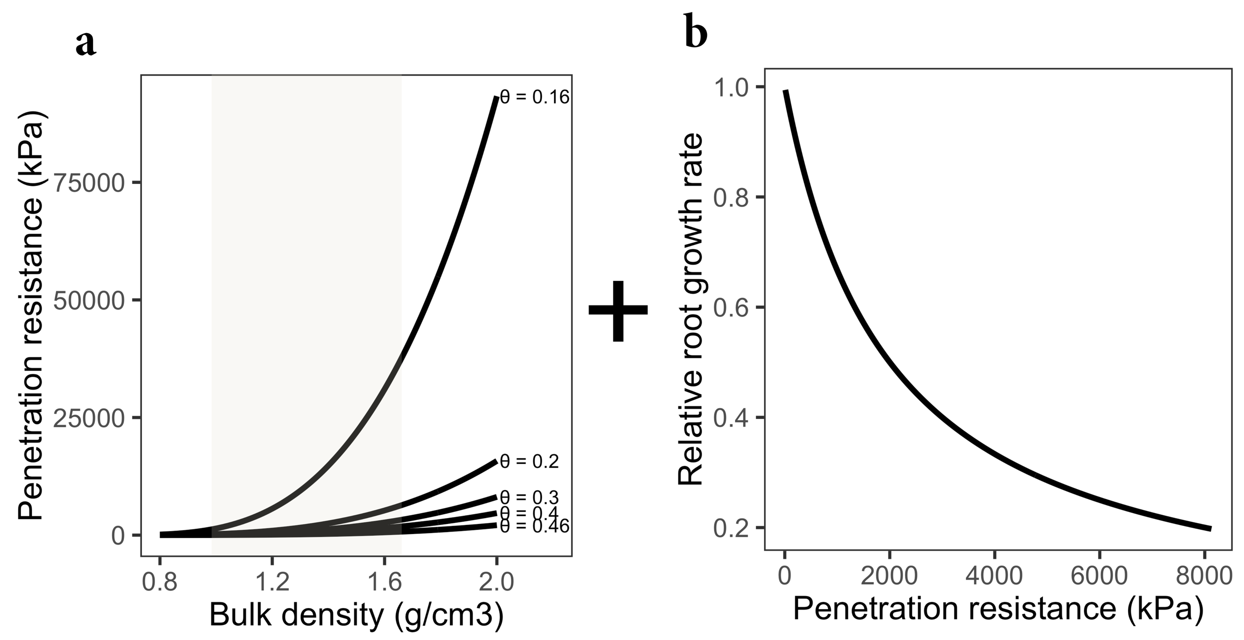
ψ = matric potential, calculated from van Genuchten

S^* = effective saturation, calculated from van Genuchten

A*, F, p, f = fitted constants

Contribution

- We updated the structural-functional root growth model *OpenSimRoot* (Postma et al. 2017, New Phyt) to include a physical model of soil impedance.
- Models with realistic soil impedance predict shallower- and shorter-rooted phenotypes than do models with uniform impedance.
- Adding a plowpan increases sensitivity to root branching angle.
- **Accounting for soil physical structure changes model predictions of root architecture.**
- Next steps: Validate against field data.



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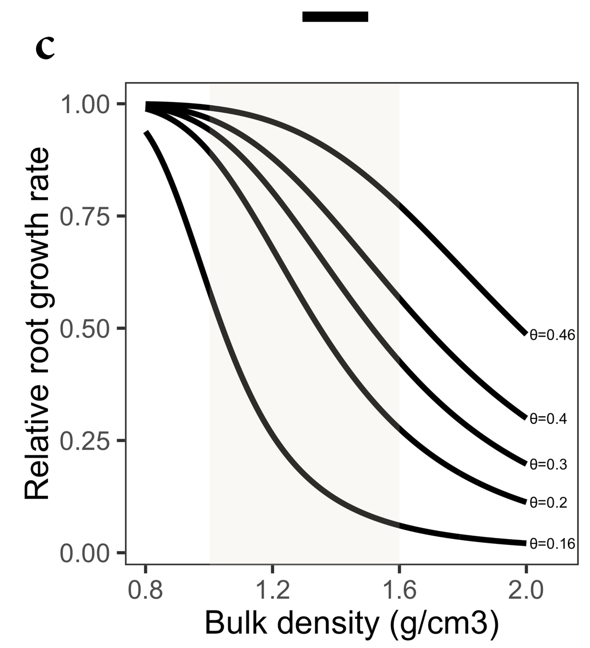
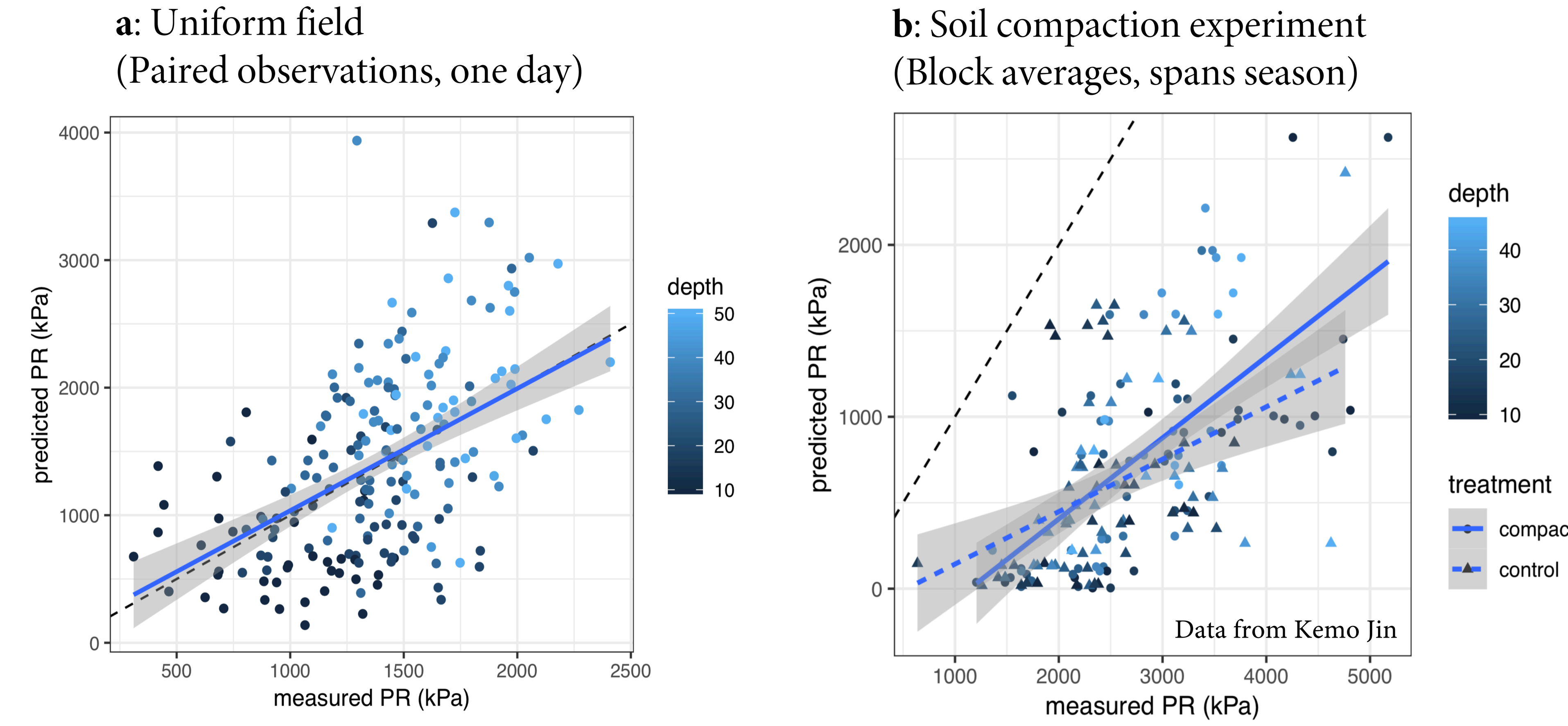
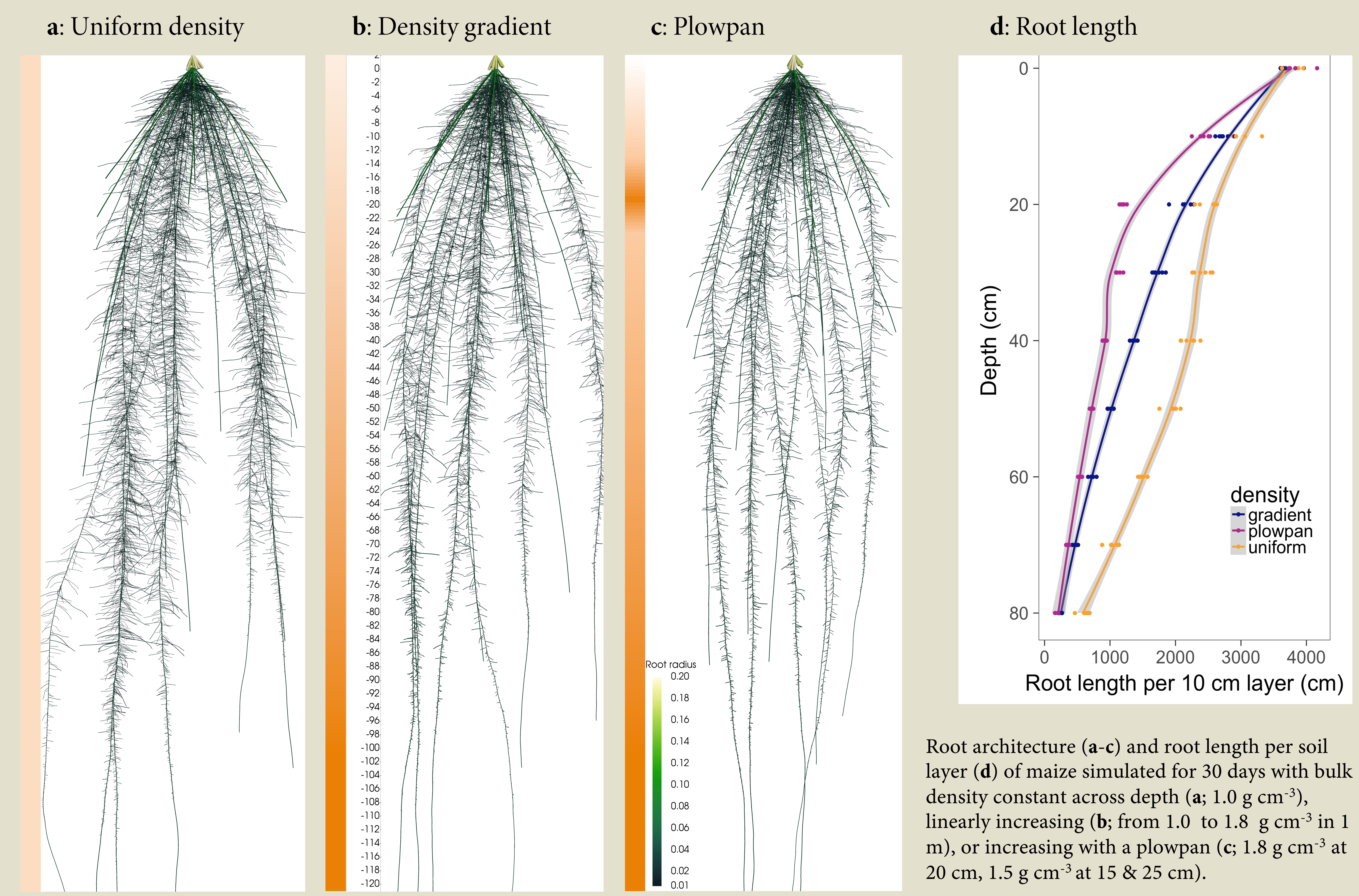


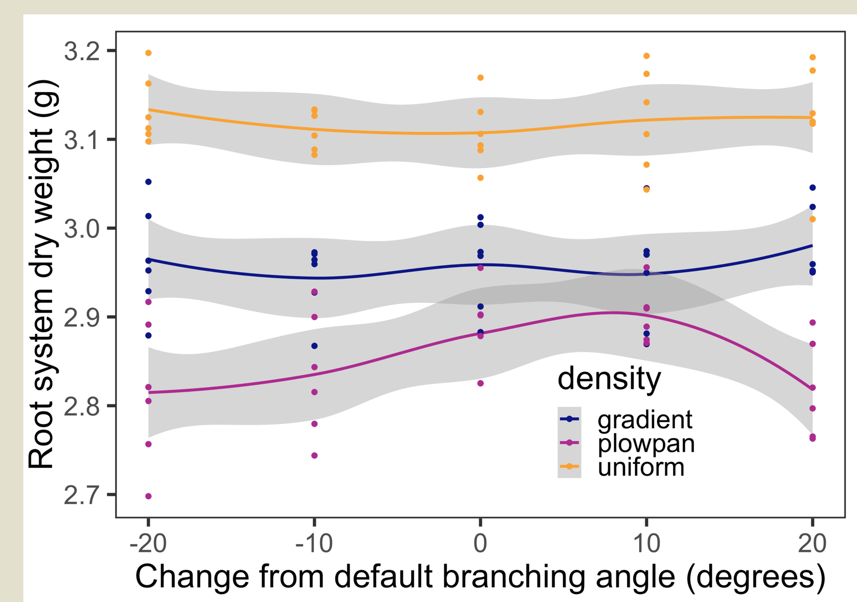
Calculation of relative growth rate in OpenSimRoot: Penetration resistance (**a**) is estimated from bulk density and water status according to the pedotransfer function of Gao et al (2016), then converted to relative growth rate (**b**) according to a user-specified root impedance function; here, we use a decreasing Michaelis-Menten with Km=2000. The resulting effect of bulk density on relative growth (c) is roughly sigmoid, with a quasi-linear portion in the range typical of agricultural soils (shaded).

Comparison of penetration resistance observed vs. predicted from bulk density and water status of a silt loam soil at Rock Springs, PA, measured as (**a**) 10-cm layers from paired 0-50 cm coring and penetrometry in a single maize field on 2017-06-27, and (**b**) daily block averages of 2.5 cm layers (7.5-50 cm) across the 2017 growing season in a soil compaction experiment.

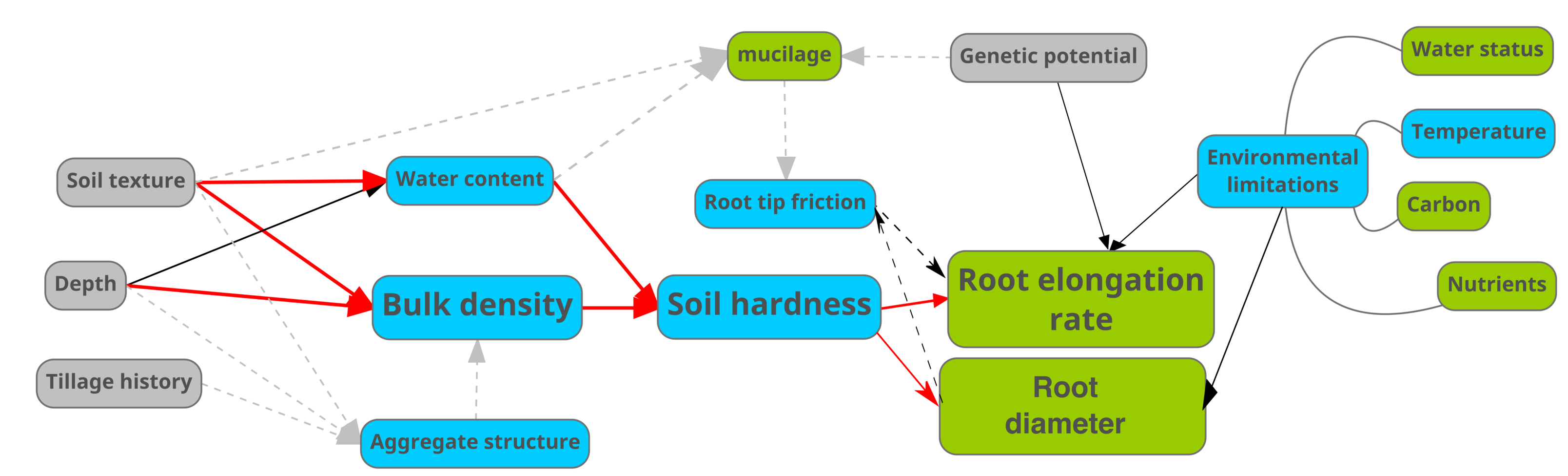




Root architecture (**a-c**) and root length per soil layer (**d**) of maize simulated for 30 days with bulk density constant across depth (**a**; 1.0 g cm-3), linearly increasing (**b**; from 1.0 to 1.8 g cm-3 in 1 m), or increasing with a plowpan (**c**; 1.8 g cm-3 at 20 cm, 1.5 g cm-3 at 15 & 25 cm).



Effect of altering root branching angle on predicted maize root mass after 30 days.



Conceptual diagram of factors affecting root growth rate in OpenSimRoot. Red arrows are links newly implemented in this study; dashed lines are planned but not yet implemented.

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