

Rewiring Roots for Resilience: Synthetic CRISPRa Circuits for Spatiotemporal Control of Phosphate Deficiency Adaptation.

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Phosphorus (P) is essential for crop growth, yet roughly half of the world's arable land has low P availability, and crops typically recover less than 15% of applied phosphate fertilizer. The rest becomes locked in insoluble soil complexes. Meeting this challenge without deepening our reliance on finite phosphate-rock reserves requires crops that can actively mine the vast pools of soil P that remain out of reach. Some plants already do this: white lupin builds dense proteoid “cluster roots” that undergo a coordinated exudative burst, flooding the rhizosphere with organic acids, phosphatases, and protons to liberate P that would otherwise remain locked in the soil. Reconstructing this strategy in major crops has long been a goal of plant biotechnology, but the trait's complexity, spanning root architecture, carbon allocation, biochemistry, and transport, has made single-gene approaches largely ineffective. In this talk, I will describe TiGAPh (Tissue-specific Gene-Activation system for Phosphorus deprivation), a programmable CRISPR-based gene circuit designed to meet this complexity on its own terms. TiGAPh functions as a genetic AND-gate, activating gene expression only when a plant is both phosphate-starved and in the correct root cell type. I will present its validation in *Arabidopsis*, showing tight, tissue-restricted activation across six distinct root domains, and our first engineered trait: a pericycle-targeted auxin circuit that converts phosphate starvation into enhanced lateral-root branching and root-hair growth, recreating key features of a natural cluster-root response. I will close by outlining how this platform is being expanded into a full multigene system, a path toward crops that acquire phosphorus more efficiently and depend less on fertilizer.