Rhizosphere Observations Optimizing Terrestrial Sequestration (ROOTS)

America's vast terrestrial resources (over 520 million hectares of crop, range and forestland) are strategic assets essential for sustainable economic growth. While advances in technology have resulted in a ten-fold increase in crop productivity over the past hundred years, soil quality has declined, incurring a soil carbon debt equivalent to 65 parts per million (ppm) of atmospheric carbon dioxide (CO_2). The soil carbon debt also increases the need for costly nitrogen fertilizer, which has become the primary source of nitrous oxide (N_2O) emissions, a greenhouse gas. The soil carbon debt also impacts crop water use, increasing susceptibility to drought stress, which threatens future productivity.

Given the scale of domestic (and global) agriculture resources, there is tremendous potential to reverse these trends by harnessing the photosynthetic bridge between atmospheric carbon, plants, microbes and soil. Development of new root-focused plant cultivars could dramatically and economically reduce atmospheric CO_2 concentrations while improving productivity, resilience and sustainability. To this end, projects in the ARPA-E Rhizosphere Observations Optimizing Terrestrial Sequestration (ROOTS) program seek to develop advanced technologies and crop cultivars that enable a 50 percent increase in soil carbon accumulation while reducing N_2O emissions by 50 percent and increasing water productivity by 25 percent.

PROJECT DESCRIPTIONS

Colorado State University – Fort Collins, CO

Root genetics in the Field to Understand Drought Adaptation and Carbon Sequestration – $6,100,000

The Colorado State University team will develop a field-deployable ground robotic platform with a suite of sensor technologies that investigate crop genetic-environment interaction and the chemical cycling of carbon and nitrogen in the soil. This will be studied at field sites in Colorado and Arizona with diverse advantages for and challenges to crop productivity. The sensing platform will allow characterization of the root systems in the ground and lead to improved quantification of soil health. The data will be managed and analyzed through the CyVerse "big data" computational analytics platform, enabling the connection of aboveground plant phenotypes with belowground soil carbon accumulation.

Iowa State University – Ames, IA

High-throughput, High-Resolution Phenotyping of Nitrogen Use Efficiency Using Coupled In-Plant and In-Soil Sensors – $1,100,000

The Iowa State University team will develop a novel technology toolset consisting of two types of sensors to accelerate plant breeding for nitrogen uptake and nitrogen use efficiency. The team will design and build a novel silicon microneedle in-plant nitrogen sensor and a microfluidic soil nitrogen sensor. Incorporating the new soil and in-plant sensors into "real world" field trials will improve and accelerate the effort to identify, select and commercial new crops with improved nitrogen use efficiency.

Lawrence Berkeley National Laboratory 1 – Berkeley, CA

Integrated Imaging and Modeling Toolbox for Accelerated Development of Root-Focused Crops at Field Scales – $2,300,000

The Lawrence Berkeley National Laboratory (LBNL) team will develop an electrical impedance-based sensor technique that uses electrical currents to determine the properties of root systems in the field. The LBNL team will incorporate electrodes into plants and soils, then employ advanced algorithms to derive phenotypic information from the sensor data. This data will be integrated with ecosystem models to identify relationships between genotype and phenotype. The technology will be applied to wheat breeding programs at field sites in Oklahoma.

Lawrence Berkeley National Laboratory 2 – Berkeley, CA

Associated Particle Imaging (API) for Non-Invasive Determination of Carbon Distribution in Soil – $2,300,000

The LBNL team will develop a tool to precisely quantify soil carbon distribution using inelastic neutron scattering. This is a major advance over existing methods because it does not require samples to be extracted and analyzed chemically. The LBNL project takes advantage of recent technical breakthroughs in compact neutron generators, using these particles to form an image of the spatial distribution of carbon and other elements in the soil to depths of 30 cm. If successful, this tool will enable measurement of changes in soil carbon stocks over time, allowing step change improvement in the evaluation and adoption of better land management practices or selection of enhanced crop cultivars.

The Pennsylvania State University – State College, PA

DEEPER: An Integrated Phenotyping Platform for Deeper Roots – $7,000,000

The Pennsylvania State University team is developing a low-cost, integrated system to identify and screen for high-yielding, deep-rooted cultivars of corn. Their key sensor innovation is to measure leaf elemental composition with x-ray fluorescence, and use it as a proxy for rooting depth. They will also develop an automated imaging system for excavated roots, allowing them to identify architectural traits of roots, and enhance a laser-based imaging platform to determine root anatomy. The combination of these technology platforms with advanced computational models developed for this program will allow PSU to determine the depth of plant roots, enabling better quantification of root biomass. As a full system platform, they will aim to develop new crop ideotypes and cultivars that can be adopted rapidly for commercial cultivation. The team will contribute data to a nationwide dataset that seeks to study the interactions between genes and the environment.

Sandia National Laboratories – Albuquerque, NM

Multi-Modal Monitoring of Plant Roots for Drought and Heat Tolerance in the U.S. Southwest – $2,400,000

The Sandia National Laboratories team will develop a set of technologies to link belowground carbon partitioning with aboveground photosynthetic measurements. They will use microneedle sensor technology, originally developed for medical applications such as glucose level monitoring, to non-destructively measure the transport and composition of plant sap and products of photosynthesis in the field. In addition, they will measure the soil chemistry near the root zone with a micro-gas chromatograph, a device used to separate and analyze individual compounds. Using data analytics and modeling, they will link these measurements together to find aboveground proxies for belowground processes. If successful, the project will allow for the selection of improved sorghum varieties with increased root biomass without excavation of roots.

Stanford University – Stanford, CA

Thermoacoustic Root Imaging, Biomass Analysis, and Characterization – $2,000,000

The Stanford University team will develop a non-contact, high throughput, thermoacoustic root imaging system where ultrasonic signals from roots are generated by radio signals and then recorded by a novel sensor array. The Stanford team will demonstrate use of the system across a variety of soil and root types in the field to map the root architecture of plants. If successful, the project will be the first low-cost, large-scale, field-based plant phenotyping solution for eventual use with a fully autonomous measurement system.

Texas A&M AgriLife Research – College Station, TX

A Field-Deployable Magnetic Resonance Imaging Rhizotron for Modeling and Enhancing Root Growth and Biogeochemical Function – $4,000,000

The Texas A&M AgriLife Research team will develop a low-cost, portable magnetic resonance imaging (MRI) system for field imaging of root architecture and soil water distribution. The system will provide high spatial resolution and allow for dynamic tracking of water movement in roots and soil. This will allow identification of plant roots with improved nutrient uptake and quantification of plant available water in the soil. The aboveground design of the imaging system will allow for easier, less invasive set up and use. The team will leverage its partners' world-class expertise in sorghum genetics and breeding, as well as cutting edge biomedical engineering and physics capabilities.

UHV Technologies – Fort Worth, TX

Low Cost X-Ray CT System for In-Situ Imaging of Roots – $2,000,000

The UHV Technologies team seeks to move 3D X-ray computed tomography, like that utilized in medicine, into the field to produce detailed root images with micron-level resolution. The UHV team will develop the necessary hardware for this system based on a unique linear X-ray tube that is compact, uses less power, and can be situated next to plants in conjunction with an X-ray detector. UHV and their partners will develop the sophisticated image processing algorithms to reconstruct complete 3D structures of root systems from the X-ray images. The UHV team aims to equip a field robot with this X-ray tube and detection equipment for automated, high throughput crop breeding operations.

University of Florida – Gainesville, FL

Rays for Roots – Integrating Backscatter X-Ray Phenotyping, Modeling, and Genetics to Increase Carbon Sequestration and Resource Use Efficiency – $6,000,000

The University of Florida team will develop a technique for phenotyping crops in the field using X-ray backscatter technology to produce images of roots without disturbing the plant or the soil. This program will study a 10-site switchgrass garden spanning growth zones from Texas to South Dakota. X-ray backscatter systems use a targeted beam to illuminate the part of the plant under observation, and sensors detect the particles reflected back to construct an image. The Florida team will build a portable, compact backscatter X-ray device capable of imaging through soil deeper than 30 cm and demonstrate the technology with deep-rooted plants. The team will build machine vision tools capable of sorting through the information returned by the X-ray detector and assembling high-quality root images. If successful, this tool would allow high-speed imaging of plant roots in a crop breeding platform that is compatible with current agriculture equipment.