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Final Scientific/Technical Report

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Project Team Members	Yuxin Wu, Eoin Brodie, William Riley, Elison Blancaflor, Xuefeng Ma, Roelof Versteeg
Project Title:	An integrated Imaging and Modeling Toolbox for Accelerated Development of Root-focused Crops at Field Scales
Program Director:	David A Lee
Principal Investigator:	Xuefeng Ma (Noble)
Contract Administrator:	Cookie Smith (Noble)
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Public Executive Summary

This project, led by Yuxin Wu at the LBNL, was proposed to develop an integrated imaging-modeling toolbox allowing for accelerated development of root-focused crops at field scales. Our approach is based on a novel root phenotyping method we termed Tomographic Electrical Rhizosphere Imaging (TERI), which provides advanced phenotyping of key root traits by sensing the electrical impedance response of roots and soil to external electrical excitations, and mapping these responses to root and soil properties.

The role of Noble Research Institute in this project is to assist TERI model establishment and validation by collecting various above- and below-ground traits data from container- and field-grown plants (mainly wheat). Over the last three years, Noble Research Institute has conducted 3 phases of experiments as proposed including: (Phase 1) greenhouse and hoop-house experiments in wheat and pecan plants grown under controlled container-grown conditions; (Phase 2) space-planted individual plant field experiment using different wheat varieties; and (Phase 3) small-plot planted field experiment using different wheat varieties, as well as using different small grains species including wheat, rye, triticale, oat and barley for increasing plant variation.

For all experiments, plants were sampled for charactering both above-ground traits and below ground root traits. The above-ground traits (biomass, grain yield, plant height, etc.) were evaluated with manual measurements and sensor predication modeling. The below ground traits were evaluated using different methods (PVP pipe, wood box, soil coiling, shovelomics, etc.) depending the growth conditions. Multiple data points were collected in each experiment according to developmental stages (from seedling stage to matured stage) of the plants. Collected data have been utilized for establishing and validating the TERI system. In addition, soil and whether data were also collected and monitored for the *ecosys* modeling.

Throughout the experiments over the last three years, Noble also assisted data collection using protypes of TERI during its development. During this last growth season (2020-2021), we adopted actual TERI in field grown plants. The current TERI system allows real-time below ground data collection and remote control for monitoring root growth, nutrient level, and water dynamics throughout the growth season. By the end of this growing season (June 2021), Noble completed all field activities involving manual sample collection, manual data collection, sensor data collection and TERI implementation as planned in the proposal.

Pending work from Noble: Due to research direction changes, Noble does not have enough time to clean all soil coil/root samples or scan root samples collected in the late spring of 2021. Upon agreement among all responsible parties, the project concluded at Noble on June 30, 2011. The remaining work of the project is to be transferred to Oklahoma State University under the supervision by Dr. Jiangqi Wen. We do not anticipate too much interruption to the project because the only remaining work is root scanning.

Acknowledgements
We sincerely thank ARPA-E for financially supporting the research of this project.

Accomplishments and Objectives

This award allowed [Noble Research Institute] to demonstrate a number of key objectives. The focus of the project was on building a [Tomographic Electrical Rhizosphere Imaging (TERI) system for Root Phenotyping at Field Scales]. A number of tasks and milestones were laid out in Attachment 3, the Technical Milestones and Deliverables, at the beginning of the project. The actual performance against the stated milestones is summarized here:

Table 1. Key Milestones and Deliverables

Tasks	Milestones and Deliverables
Task 7: Validation of TERI for Root-Focused Plant Breeding Applications in Wheat M7.1 wheat cultivars selection and basic root biology studies under controlled soil and nutrient conditions.	Year 1: Completed greenhouse and hoop-house experiments in wheat and pecan plants grown under controlled container-grown conditions; Year 2: Completed space-planted individual plant field experiment using different wheat varieties; Year 3: Completed small-plot planted field experiment using different wheat varieties, as well as using different small grains species including wheat, rye, triticale, oat and barley for increasing plant variation. Specifically, in Year 1 and year 2, we found that axial root number was significantly correlated with shoot biomass at the early stage under deficit irrigation. These results indicate that root number was indirectly selected to increase shoot biomass at the early stage under drought conditions. Our finding that axial root number is correlated with enhanced shoot biomass at the early growth stages, was verified by first, re-analyzed published datasets from the Triticeae Cooperative Agricultural Project (T-CAP) population. The results show that dry shoot biomass averaged from different decades exhibits an increasing trend over time (Fig. 1A). We also found similar trends within the five historical cultivars this season (Fig. 1B). Even though shoot biomass did not increase consistently, the two most recent cultivars-TAM111 and Garrison, had higher shoot biomass than the older cultivars. Interestingly, we found that root number also had an increasing trend

	over time (Fig. 1C). The correlation analysis shows that shoot biomass was significantly correlated with root number (Fig. 1D). Based on hoop house and field experiments from two seasons, we have strong evidence showing that wheat breeding has indirectly selected for root number to increase shoot biomass at the early stage under drought conditions. Such an observation has important implications for forage breeding and **reinforce the need for non-destructive root phenotyping platforms such as TERI.** In year 3, we adopted the TERI in different wheat varieties, as well as other small grains species including rye, triticale, oat and barley for increasing variation of root system architecture and above biomass. Seasonal progress was reported in the quarterly reports, and final data will be analyzed by OSU and LBNL.

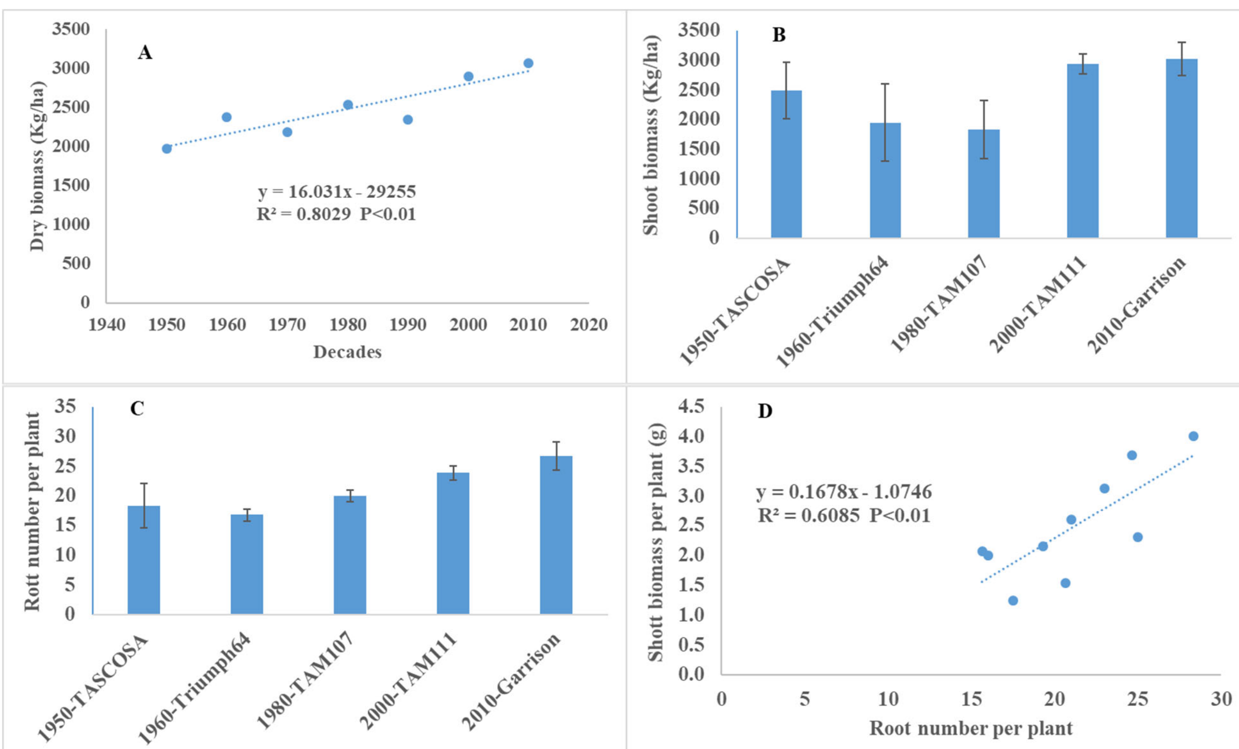

Figure 1: Plant (including root) architecture changes of wheat cultivars over time (A, data from Kim et al., 2016, Crop Science, 56: 1-9.) and in the five historical cultivars used in this study (B), root number of the five historical cultivars (C) and correlation analysis between root number and shoot biomass (D).

Project Activities

As the project role of Noble Research Institute is being transferred to Oklahoma State University, this report only serves as a periodic summary of the field tack being completed to date.

Transferring data and samples to Oklahoma State University is completed.

Project Outputs

This is not a final report of the project. Project outputs will be reported in the final report from Lawrence Berkeley National Laboratory.

Follow-On Funding

Will be clarified in the final report from Lawrence Berkeley National Laboratory.