Real-Time Live Phenotyping – A Path to Next Generation Breeding & Farming

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Monitoring plants 24 hours a day in real time to identify crop problems early on can make the difference between saving a crop and losing it. It is not science fiction anymore. With the application of artificial intelligence (AI) and remote sensing in agriculture, next generation breeding and farming come closer to reality. Specifically, an interdisciplinary team of scientists, geneticists from the Plant Science Research Unit of the USDA-ARS in St. Paul, MN, with researchers at North Carolina State University in the Department of Crop and Soil Sciences and the Department of Electrical and Computer Engineering, and scientists in the Precision Sustainable Agriculture (PSA) project, are developing a real-time phenotyping system to remotely monitor alfalfa growth through all four seasons.

Alfalfa is the most widely grown perennial forage crop in the U.S. It plays critical roles in livestock nutrition, protecting water and soil resources, enhancing soil fertility, and sequestering soil carbon. But alfalfa biomass yield has been stagnant over the past decade. Additionally, winterkill reduces yield and stand life, making farmers reluctant to invest in producing alfalfa. A new method using DNA markers for genomic selection is a promising option to break the bottleneck of yield gain and increase winter hardiness in alfalfa cultivars. But effectively applying genomic selection depends on accurate phenotyping, or measurement of plant traits. Current phenotyping technologies are usually single time-point measurements that are labor-extensive and subjective to human error. In this regard, high throughput machine learning-based AI technologies can phenotype plants in real time without affecting development and also detect stress before symptoms are visible.

Constructing a real-time phenotyping AI system for forage breeding. The real-time phenotyping system has four parts: data acquisition via a StressCam, transfer of data by WiFi, machine learning prediction in the cloud, and real-time decision tools to breeders and farmers. The core part of the system is the StressCam computer, ~$150 each with a tiny WiFi-enabled camera for taking pictures of plants in a field. The camera is connected to a timer that controls the frequency of image capture. The StressCam runs a machine learning algorithm on the photos to analyze them for indications of stress. Then it sends this information to a web platform for farmers, breeders, and researchers to monitor their fields. The system is solar powered and can be used for both experimental plots and commercial farmland.

What can real-time phenotyping bring to breeders and farmers? AI-based real-time plant phenotyping is an essential and integral part of a holistic phenomics approach to address the complex genotype x environment x management interaction so that the best cultivars are planted on the right farmland to maximize profitability.

There are an extensive number of traits that must be measured to understand which specific traits contribute to improvements in alfalfa yield, yield stability, resource capture and use (e.g., water and nitrogen), and resistance to abiotic or biotic stresses.

For breeders, real-time live phenotyping can measure these traits hundreds of times during the growing season. Combined with genetic information, this will allow breeders to identify regions of the genome-controlling traits and help them make more informed decisions in selecting plants for cultivar development. Real-time phenotyping will be even more critical for breeding for cold tolerance in alfalfa. Breeders will be able to phenotype plants as

they break dormancy and AI-based live phenotyping can detect plant responses invisible to human eyes.

For farmers, real-time monitoring of crops enables detection of early symptoms of disease, insects, drought, and nutrient deficiencies as well as yield and quality for timely management and harvest time optimization. These decisions can be made with a smartphone or a tablet.

Where are we in applying real-time phenotyping systems for forage breeding? The PSA project has built, implemented, and evaluated three different versions of more than 50 StressCams during the summers of 2019 and 2020, creating databases to identify stress levels in corn and soybean with an accuracy between 75% and 90%, respectively. Nine StressCam systems, one in the lab and eight in the field, were installed in St. Paul this fall to test the system's capability of monitoring alfalfa plots and to test its function in low temperatures and in different conditions than the StressCam was tested in the past. Live images from the StressCam in Spring 2021 will measure early growth from experimental plots with different amounts of stubble and number of plants. A larger experiment will be deployed in Fall 2021. The low cost of the system makes it feasible to expand it on a large scale for breeding experiments and in commercial farmland. In 2022, the real-time phenotyping AI system will be implemented nationwide by the PSA research network, a network of farms and research stations in 22 states supported in part by a USDA Agriculture and Food Research Initiative grant for the development of resilient agricultural systems. For alfalfa, we are expecting to install 50 cameras in 2022. We can envision that genotypic, phenotypic, environmental, and production management data will be harmonized and optimized for maximizing profitability and environmental sustainability in the next five years.