



Advanced Plant Phenotyping Laboratory

The Advanced Plant Phenotyping Laboratory, or APPL, houses a unique greenhouse system at the US Department of Energy's (DOE's) Oak Ridge National Laboratory (ORNL) that is accelerating fundamental science investigations in bioenergy and agriculture. APPL uses robotics and sensors to automatically move plants through multiple imaging stations for measuring, or phenotyping, plant growth, health, and traits such as drought tolerance over time. APPL measures plant characteristics using a broad spectrum of light from invisible ultraviolet to visible colors to infrared. APPL is one of the most diverse plant phenotyping systems in the world.

Turning pixels into knowledge

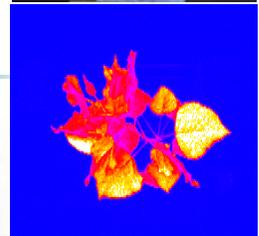
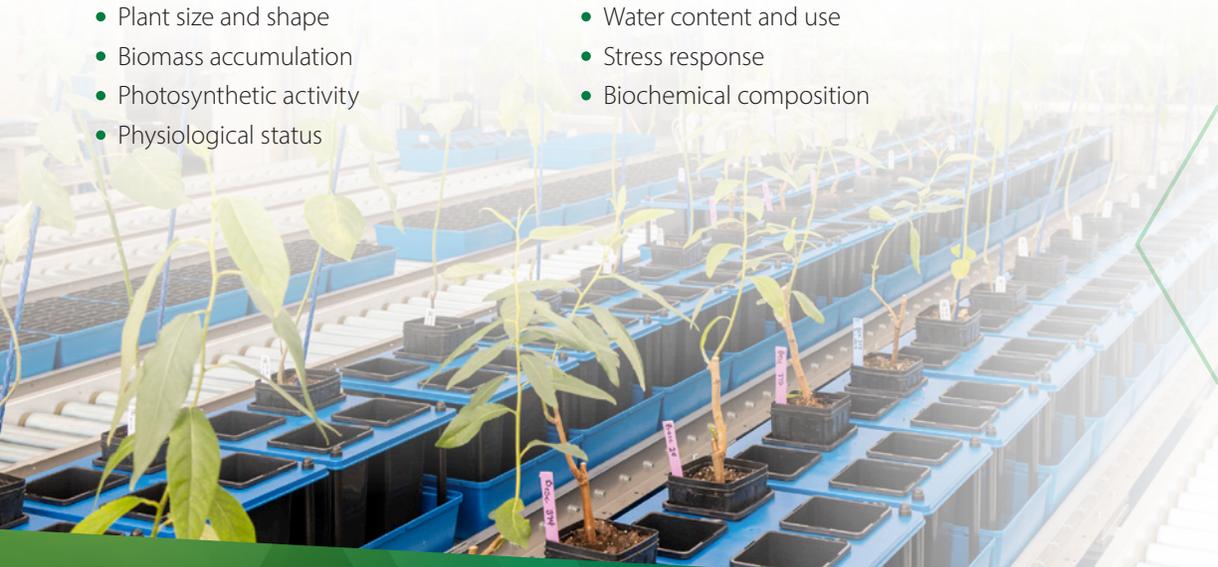
APPL uses sophisticated cameras and lights to capture plant size, shape, composition, and function at the pixel level, extending measurements beyond what the human eye can see to create a digital twin of each plant. The system propels up to 500 plants along more than 700 ft of track, automating measurements and analyses for greater throughput and in-depth characterization than possible using manual methods. By leveraging ORNL capabilities in scientific computing and artificial intelligence, billions of pixels across thousands of images can relate plant growth and function to changing environmental conditions, time, and underlying genetics.

Integrating APPL's capabilities with the wealth of genomic data about plants and microbes, which is generated through, for example, the DOE Center for Bioenergy Innovation and the DOE Plant-Microbe Interfaces Scientific Focus Area at ORNL, enables identification of specific genes for applications in synthetic biology, such as engineering hardier crops.

R&D: Lights, camera, action

APPL provides users with access to state-of-the-art plant phenotyping capabilities. With five imaging stations covering dynamic chlorophyll fluorescence, RGB (red, green, blue), 3D laser scanning, and thermal, multispectral, and hyperspectral imaging, APPL enables unique insights over time about the following:

- Plant size and shape
- Biomass accumulation
- Photosynthetic activity
- Physiological status
- Water content and use
- Stress response
- Biochemical composition



Multiple measurements can be gathered at the same time on a single plant.

System Capabilities

Dynamic chlorophyll fluorescence imaging system

—Uses pulse amplitude modulated (PAM) technology, which allows the full range of chlorophyll fluorescence parameters to be measured. PAM fluorescence systems measure fluorescence resulting only from excitation of the sample from the measuring light (flashes), and ambient light has no effect.

Thermal imaging station—Average, standard deviation, median, and minimal and maximal temperatures are obtained across the whole plant surface. Housed in a light-proof cabinet with automatic doors, this station includes a light source to induce dynamic responses so that the camera can be used to assess stomatal activity and/or water distribution within plants.

Near-infrared camera—Images light absorption by water. Monitors water at the 1450 nm absorption peak and monitors a reference at 940 nm. A homogenous LED light source, optimized for near-infrared measurements, provides the required irradiance conditions.

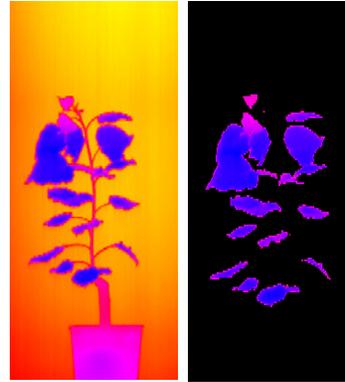
3D plant modeling camera—Morphometric and color analyses may be conducted with equal effectiveness on monocotyledonous and dicotyledonous plants, with both top-view and side-view image acquisition and processing.

Hyperspectral imaging station—Includes a visible and near-infrared camera with a range of 350–900 nm and a short-wave infrared camera with a range of 900–1700 nm. The cameras allow the user to acquire a full scan across the entire spectral range for each pixel of the image.

Automated conveyor system—For growth, randomization, watering, and weighing of plants in the greenhouse, and for transport of plants from the cultivation zone in the greenhouse to the imaging circle in the headhouse. Plants may be in pots or trays and may have dimensions up to 1.3 m tall and 0.5 m wide. Watering and weighing may be done with or without imaging.

Additional capabilities—System is expandable with potential additional capabilities, including anomaly detection and the ability to automate sample collection with the system by using lasers to cut sections of leaves and drop them into solution to initiate 'omics analyses.

Thermal Infrared



Without Mask

With Mask

Thermal infrared cameras detect long-wave infrared light that is emitted by leaves in a temperature-dependent intensity.

APPLICATIONS

- Leaf surface temperature visualization
- Transpiration over plant surface
- Stomatal activity

RGB



Without Mask

With Mask

The mask for any image is used to calculate parameters based solely on plant area; this eliminates the background. The mask can be adjusted to only analyze a specific leaf, as well as other specific elements of a plant.

APPLICATIONS

- Plant growth dynamics
- Plant morphology (shape, structure)
- Color properties of each plant

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