Novel analytical tools developed by SMART key to next-generation agriculture

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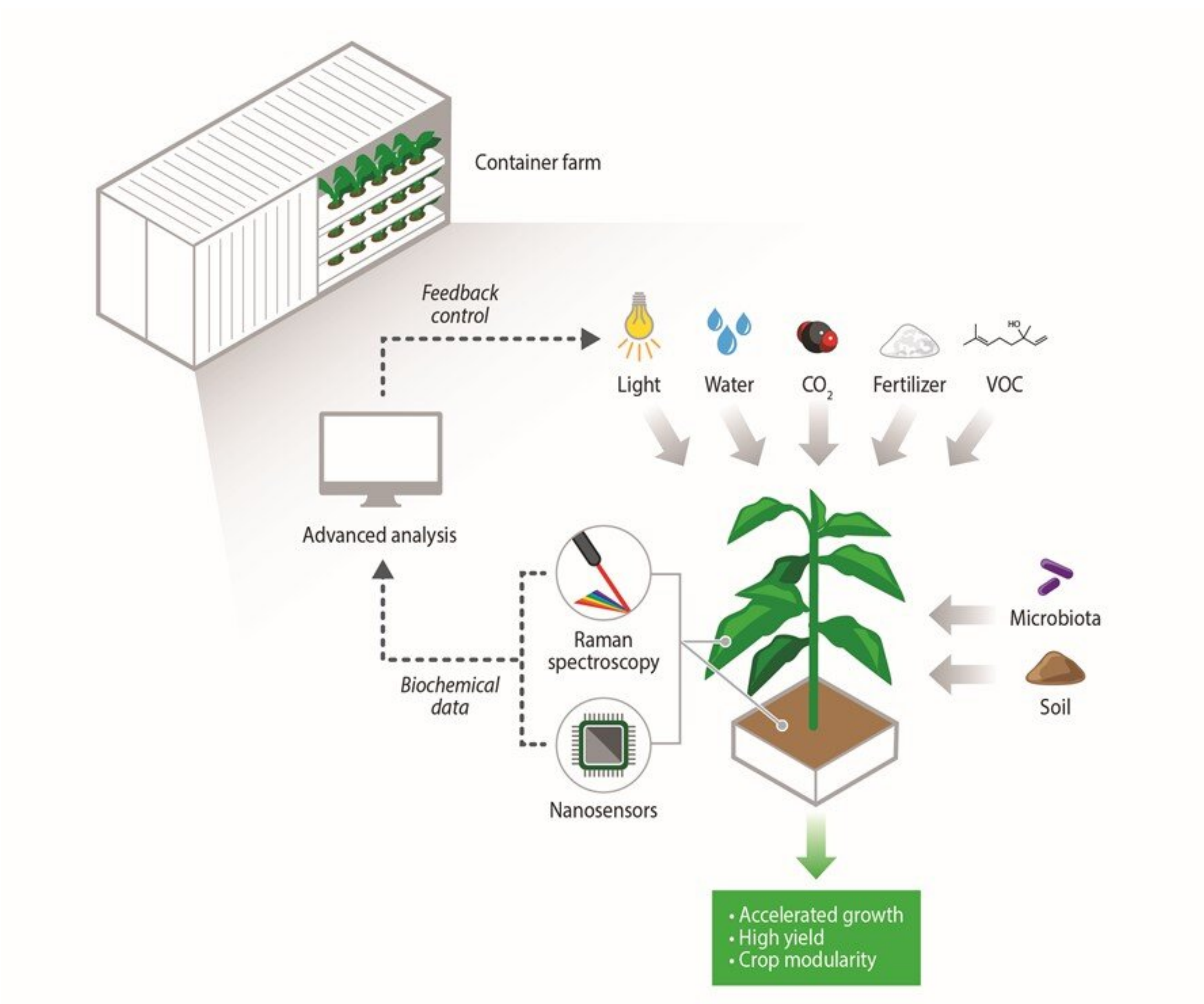

Species-independent analytical platforms can facilitate the creation of feedback-controlled high-density agriculture. Credit: Betsy Skrip, Massachusetts Institute of Technology

Researchers from the Disruptive & Sustainable Technologies for Agricultural Precision (DiSTAP) Interdisciplinary Research Group (IRG) of Singapore-MIT Alliance for Research and Technology (SMART), MIT's research enterprise in Singapore, and Temasek Life Sciences Laboratory (TLL), highlight the potential of rapid and non-destructive analytical tools that provide tissue-cell or organelle-specific information on living plants in real time and can be used on any plant species.

In a perspective paper titled "Species-independent analytical tools for next-generation agriculture," published in the scientific journal *Nature Plants*, SMART DiSTAP researchers report that they used two engineered plant nanosensors and portable Raman spectroscopy to detect biotic and abiotic stress, monitor plant hormonal signaling and characterize soil, phytobiome and crop health in a non-invasive or minimally invasive manner. The researchers discuss how the tools bridge the gap between model plants in the laboratory and field application for agriculturally relevant plants. They also provide an assessment of the future outlook, economic potential and implementation strategies for the integration of these technologies in future farming practices.

According to U.N. estimates, the global population is expected to grow by 2 billion within the next 30 years, giving rise to an expected increase in demand for food and agricultural products to feed the growing population. Today, biotic and abiotic environmental stresses such as plant pathogens, sudden fluctuations in temperature, drought, soil salinity, and toxic metal pollution—made worse by climate change—impair crop productivity and lead to significant losses in agriculture yield worldwide.

An estimated 11 to 30% yield loss of five major crops of global importance (wheat, rice maize, potato, and soybean) are caused by crop pathogens and insects; with the highest crop losses observed in regions already suffering from food insecurity. Against this backdrop, research into innovative technologies and tools are required for sustainable agricultural practices and meet the rising demand for food and food security—an issue that has drawn the attention of governments worldwide due to the COVID-19 pandemic.

The Plant nanosensors were developed at SMART DiSTAP. They are smaller than the width of a hair and can be inserted into the tissues and cells of plants to understand complex signaling pathways. The portable Raman spectroscopy, also developed at SMART DiSTAP, is a portable laser-based device that measures molecular vibrations induced by laser excitation, producing highly specific Raman spectral signatures that provide a fingerprint of a plant's health. These tools are able to monitor stress signals in short time scales, ranging from seconds to minutes, allowing for early detection of stress signals in real-time.

"The use of plant nanosensors and Raman spectroscopy has the potential to advance our understanding of crop health, behavior, and dynamics in agricultural settings," said Dr. Tedrick Thomas Salim Lew, the paper's first author and a recent graduate student of the Massachusetts Institute of Technology (MIT). "Plants are highly complex machines within a dynamic ecosystem, and a fundamental study of its internal workings and diverse microbial communities of its ecosystem is important to uncover meaningful information that will be helpful to farmers and enable sustainable farming practices. These next-generation tools can help answer a key challenge in plant biology, which is to bridge the knowledge gap between our understanding of model laboratory-grown plants and agriculturally-relevant crops cultivated in fields or production facilities."

Early plant stress detection is key to timely intervention and increasing the effectiveness of management decisions for specific types of stress conditions in plants. The development of these tools capable of studying plant health and reporting stress events in real-time will benefit both plant biologists and farmers. The data obtained from these tools can be translated into useful information for farmers to make management decisions in real-time to prevent yield loss and reduced crop quality.

The species-independent tools also offer new study opportunities in plant science for researchers. In contrast to conventional genetic engineering techniques that are only applicable to model plants in laboratory settings, the new tools apply to any plant species which enables the study of agriculturally-relevant crops previously understudied. The adoption of these tools can enhance researchers' basic understanding of plant science and potentially bridge the gap between model and non-model plants.

"The SMART DiSTAP interdisciplinary team facilitated the work for this paper and we have both experts in engineering new agriculture technologies and potential end-users of these technologies involved in the evaluation process," said Professor Michael Strano, the paper's co-corresponding author, DiSTAP co-lead Principal Investigator, and Carbon P. Dubbs Professor of Chemical Engineering at MIT. "It has been the dream of an urban farmer to continually, at all times, engineer optimal growth conditions for plants with precise inputs and tightly controlled variables. These tools open the possibility of real-time feedback control schemes that will accelerate and improve plant growth, yield, nutrition, and culinary properties by providing optimal growth conditions for plants in the future of urban farming."

"To facilitate widespread adoption of these technologies in agriculture, we have to validate their economic potential and reliability, ensuring that they remain cost-efficient and more effective than existing approaches," the paper's co-corresponding author, DiSTAP co-lead Principal Investigator, and Deputy Chairman of TLL Professor Chua Nam Hai explained. "Plant nanosensors and Raman spectroscopy would allow farmers to adjust fertilizer and water usage, based on internal responses within the plant, to optimize growth, driving cost efficiencies in resource utilization. Optimal harvesting conditions may also translate into higher revenue from increased product quality that customers are willing to pay a premium for."

Collaboration among engineers, plant biologists, and data scientists, and further testing of new tools under field conditions with critical evaluations of their technical robustness and economic potential will be important in ensuring sustainable implementation of technologies in tomorrow's agriculture.

DiSTAP Scientific Advisory Board Members, Professor Kazuki Saito, Group Director of Metabolomics Research Group at RIKEN Center for Sustainable Resource Science, and Hebrew University of Jerusalem Professor, Oded Shoseyov also co-authored the paper.

More information: Tedrick Thomas Salim Lew et al. Species-independent analytical tools for next-generation agriculture, *Nature Plants* (2020). DOI: 10.1038/s41477-020-00808-7. www.nature.com/articles/s41477-020-00808-7

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