Optical sensors enhance plant nutrient monitoring

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Ensuring that plants have all the nutrients and water that they need is a major concern in agriculture. Two fiber-optic sensor systems could provide new ways to monitor whether plants are deficient in any essential nutrients. These sensors work without destroying the plants under investigation or putting them under stress.

Plant nutrition is very important for plant survival and growth. Lack of essential nutrients will seriously affect the growth of the plant. For this reason, nutrient management, as well as the environment and pest control, is a major issue for farmers and agriculturalists.

The conventional ways to detect plant nutrient content are plant analysis and tissue testing. However, these methods are time consuming, subjective, and require sample preparation or specialist handling. They are also destructive.

The increasing emphasis on non-destructive testing methods has prompted the development of devices such as the chlorophyll meter which directly measures leaf transmittance and relates it to the nitrogen (N) status in the plant.\(^1\) Research has also focused on finding specific wavelengths, or vegetation indices, from the leaf reflectance spectrum. These can characterize chlorophyll or pigment status.\(^2\) However, in most studies, plants or plant seedlings have been subjected to prolonged periods of stress. This means that such approaches preclude the possibility of predicting plant stress.

Two novel fiber-optic sensor systems for non-destructive plant biotechnology monitoring applications have been developed. The first is a nutrient stress analyzer.\(^3\) This exploits the spatial signatures that are unique to specific elemental deficiencies in plants to identify nutrient deficiency. The second device is a green fluorescent protein (GFP) analyzer\(^4\) that serves as a fluorescent protein marker-cum-optical system for identifying genetically-modified plants.

The nutrient stress analyzer is based on reflectance spectroscopy with novel strategies for spectrum analysis. One of the features of interest in the leaf reflectance spectra is the red-edge inflection point, which is the maximum first derivative of the reflectance spectrum in the 680—750nm region. This value shifts to longer wavelengths in control plants and to shorter wavelengths in certain nutrient-stressed plants, as the plant matures. The spectra can also be transformed into three color values, to enable different types of nutrient stress to be distinguished. In addition to identifying nutrient deficiency, the nutrient stress analyzer enables remote online feedback control in fertilizer applications (pertaining to both soil-based and hydroponic-based crop systems). This helps to optimize crop yield and resource utilization, while minimizing environmental damage as a result of excessive fertilizer use.

The GFP analyzer negates the controversial use of antibiotic resistance-marker genes and is designed to address the environmental and safety concerns in the genetic engineering of plants. Moreover, the system allows the expression level of the introduced gene to be quantified. This facilitates rapid and non-destructive evaluation of foreign gene activity in transformed lines. This approach can also be incorporated into risk assessment programs for field-released genetically modified plants. This helps to precisely monitor trans-gene movement in the environment.

The idea of the GFP system is being exploited to develop transgenic ‘indicator plants’ for concomitant use with a fiber-
optical spectroscopic system to allow early detection of water-deficit conditions in field crops. A GFP-transformed plant emitted green fluorescent light once the plant had been subjected to water stress. In contrast, a wild-type plant showed only the red auto-fluorescence, as seen in Figure 1.

Sub-optimal management of crop-nutrient requirements poses a major constraint in commercial crop production for food, medicine, or valuable plant extracts. The combination of optical sensing and plant biotechnology gives more promising methods for these applications. Our nutrient stress analyzer helps to predict nutrient stress non-destructively, while the GFP analyzer helps to understand the gene expression of plants. The development of ‘indicator plants’ has also been proposed as a way to assist in plant-water stress monitoring.

Our next step will be to extend the system functionality for further stress detection. We will also try to apply the systems to areas other than plant-health monitoring, such as medical applications.

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