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Real-time x-ray fluorescence analysis of crop canopy to spatially assess phytoextraction efficiency and subsurface status of low-Z elements: a case study for phosphorus

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Leaf analysis has been extensively used to interpret results of nutrient supplementation studies about crop growth and yield responses, and to define availability thresholds for a wide range of soils and climatic conditions. The compositional results reflect the nutritional status, uptake efficiency, and the geo-chemical environment of the element in the subsurface. An X-ray fluorescence (XRF)-based proximal sensing approach was evaluated and proposed for real-time determination of water content and element-specific composition of corn seedling leaves, which was comprised mostly of essential macronutrients of low-atomic number Z, such as phosphorus (P) or potassium. Intensities of scattered radiation associated with the X-ray tube Ag anode were significantly correlated with leaf water content (θ_w), which was used to normalize fluorescence intensities of P. Crop canopy water status was also obtained as ancillary data. The θ_w - P relative concentration relationship was best described by a sigmoidal function (r^2 = 0.938 and RMSE=0.02). The Ag-Lα line was deemed to be effective for normalizing the intensities of Kα lines of P and other low-Z elements, in addition to the commonly used Kα and Kβ lines. Its intensity was significantly correlated to leaf water content and was used to develop calibrations and obtain P concentration on a dry weight basis and unbiased estimates of crop P status. Therefore, the *in situ* fluorescence sensing system presents a new paradigm in nutrient management to re-evaluate calibrations of observed crop responses against those predicted by current soil testing and fertility recommendations. Updates to the rates of supplemental P and crop growth response relationships are critically needed as crop cultivars, supplemental P sources, or alternative soil-crop management systems are continually changing. Changes in soil microenvironments that are site- or field-specific, and climate are expected to continue to be the norm and can modify those soil-plant relationships. The high-throughput of hand-held XRFS enhances our ability to make management adjustment, particularly at the short early stages of growth, when crop plants are most susceptible to P deficiency. The precision of macronutrient management can be applied at a field-specific scale. As the process can be repeated for each growing season, the knowledge base of soil fertility, crop extraction efficiency and uptake, and elemental availability can only grow in time to improve the predictability of site-specific plant responses to given yield goals and levels of nutrient and soil management inputs. Matching nutrient supply to actual levels needed by the crop minimizes loss of excess agricultural inputs and reduces the risks of adverse impact on the health of the surrounding soil and water resources.