Monitoring
Proximal Sensing

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Co-funded by the Horizon 2020 programme
of the European Union

DT-ICT-01-2019
Smart Anything Everywhere Area 2

www.smart4all-project.eu
Grant Agreement: 872614

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- Proximal sensing
- Proximal crop sensors
- Proximal sensors for crop biotic stresses
- Proximal sensors to measure crop abiotic stresses
- Proximal soil sensors

Proximal sensing

- In comparison with remote sensing, with proximal sensing, the sensor is placed in direct contact or within a distance of 2 m from the target.
- For soil and crop, proximal sensors can be classified as portable handheld, or online.
- In the portable version, the number of samples can be limited, compared with those collected by the online systems, which can reach up to 1000 readings per hectare.

Proximal crop sensors

- Proximal crop sensors are used to measure plant health in natural, silvicultural, and agricultural ecosystems.
- In situ methods include leaf-level to canopy-level measurements from various platforms like tripods, vehicles, forklifts, or cranes.
- Optical, mechanical and ultrasonic sensor technologies are commonly used.
  - Data is 2D representations of the real world in a single (monochromatic) or more (multispectral or hyperspectral) spectral regions.

Proximal crop sensors

- Thermography is a technique that captures 2D thermal radiation images, covering the range from 3 to 100 mm.
- Temperature of a plant can be estimated by the thermal radiation captured by a thermal camera.
  - When the leaf stomata close during the daytime, CO_2 and H_2O are not exchanged, causing an internal greenhouse effect.
- Irradiating chloroplasts with blue or actinic light (420 nm) will result in some reemission of the absorbed light by the chlorophyll.
  - The ratio of reemitted light to irradiation depends on the ability of the plant to metabolize the harvested light.

Proximal sensors for crop biotic stresses

Weed detection

- Weeds and crops have different shapes, and weed identification is potentially possible using advanced image processing methods.
- Weedseeker technology has shown that herbicide application rates can be reduced by 90% relative to uniform application rates.
  - It uses an active light sensor emitting red and NIR radiation to detect weeds.

Weed detection

- Digital imaging by use of optical sensors provides the ability for real-time detection with increased accuracy.
- The detection of crop plants is based on combining color and texture.
    - This approach is used for site-specific herbicide spraying.
- Crop identification is a task that complements weed detection.
    - It is used for site-specific herbicide spraying as well as mechanical weeding systems.

Case studies

Weed(s)	Crop(s)	Wavelength, nm	References
Chenopodium album, Polygonum convolvulus, Aethusa cynapium	Sugar beet, potatoes	NIR (660–1060)	Borregaard et al. (2000)
Amaranthus chlorostachys, Chenopodium album, Conringia orientalis, Rapistrum rugosum	Sugar beet	VIS (green and red bands)	Bakhshipour et al. (2017)
Abutilon theophrasti Medic. Grasses; mixed weeds	Corn, soybean	Red (675.98 and 685.17) NIR (743.93 and 830.43)	Goel et al. (2002)
Ranunculus repens, Cirsium arvense, Sinapis arvensis, Stellaria media, Tarraxacum officinale, Poa annua, Polygonum persicaria, Urtica dioica, Oxalis europaea, Medicago lupulina	Maize	Red (620–640) NIR (740–760)	Pantazi et al. (2016b)
Various species	Sugar beet	VIS-NIR	Lottes et al. (2017)
Amaranthus rudis, Kochia scoparia, Chenopodium album	Greenhouse experiment	Red and ed-edge (640, 676, 730) NIR (1078, 1435, 1490 and 1615)	Shirzadifar et al. (2018)

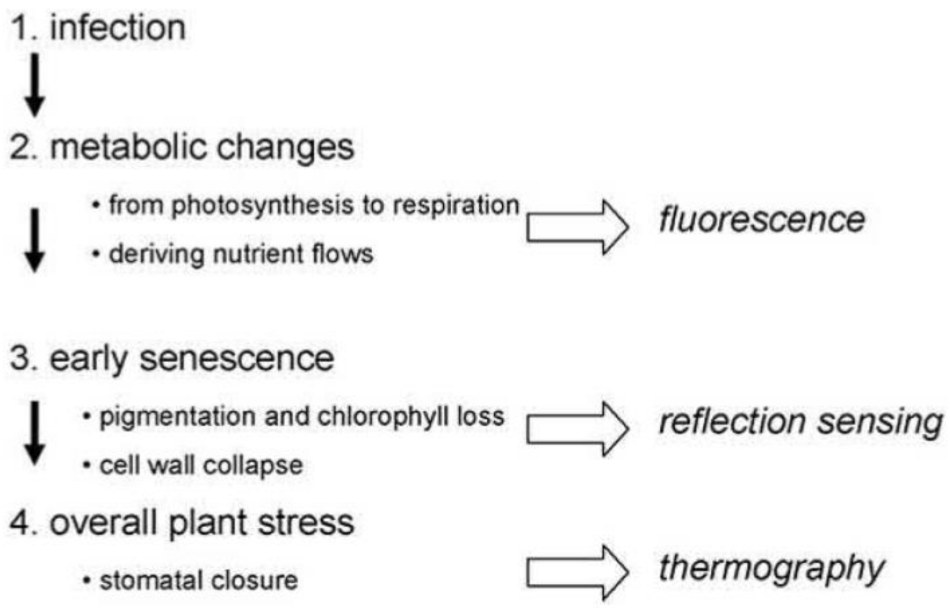
VIS-NIR, visible and near infrared; Vis, visible; NIR, near infrared.

Plant disease detection in field conditions

- Plants have different responses to light, which are referred to as optical characteristics.
- Any disease that causes enough plant stress to distort the reflectance characteristics of the crop leaf is a candidate for sensing detection.
- Disease recognition methods can be realized based on light reflection for different wavelengths or by combining wavelengths through mathematical calculations.
- Intact crops are generally green because green wavelength (ca. 550 nm) is reflected by photoactive pigments, in contrast to the blue and red wavelengths that are absorbed during photosynthesis.

Plant disease detection in field conditions

- The most important measurement techniques for the detection of foliar infections are shown briefly in the figure.
- Fluorescence is the most appropriate technique during the earliest stage of infection.
- Pathogen propagules may be detected in various parts of the spectrum, depending on the impact of the pathogen.



Disease detection using light reflection

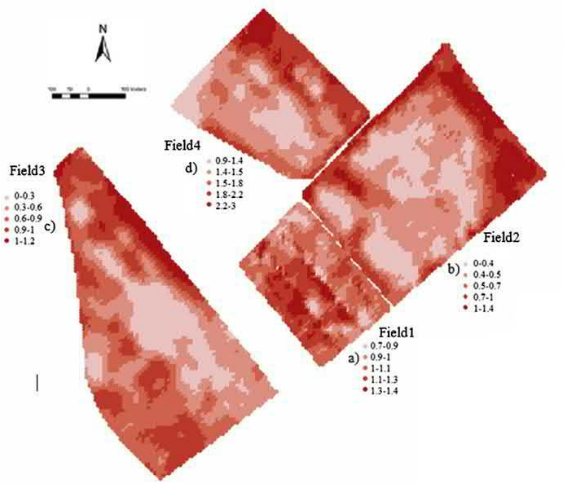
- Different wavelengths of light can be used to detect different diseases in plants.
- Infected plants were initially characterized by reflectance changes in chlorophyll absorption bands (470 and 670 nm) and NIR spectral range.
- Like fungi and bacterial diseases, insect attacks can also be detected with reflectance sensors.
- Insect attacks on plants can cause rapid death and senescence, and radical spectral changes may be observed.
- The effectiveness of the detection of diseases depends on the algorithms used for data processing.
  - Hyperspectral imaging methods can be used for detecting crop diseases.

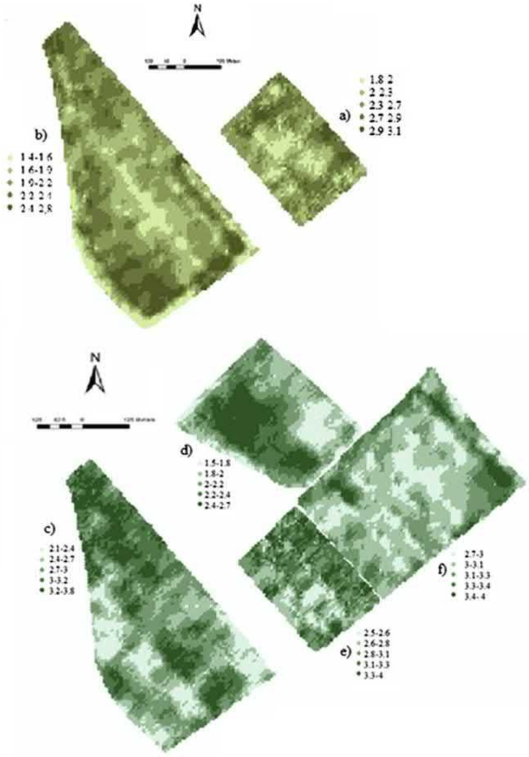
Case study

- Yellow rust and fusarium head blight cause significant losses in wheat and barley yields.
- Mapping the spatial distribution of these two fungi diseases at high sampling resolution is essential for variable rate fungicide application (VRFA) and selective harvest (SH).
- An online mobile system is necessary to inform VRFA or SH. The hyperspectral camera consists of 1608 pixels, with a spectral range of 400-1000 nm.

Case study

Online measured maps of fusarium head blight (left) and yellow rust (right).



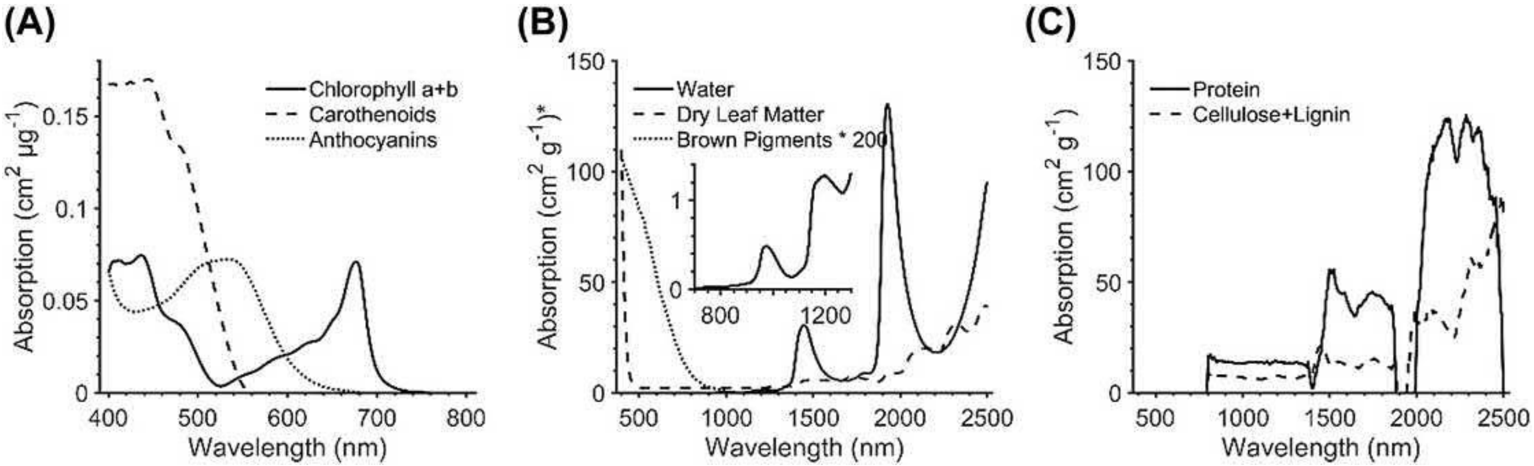


Proximal sensors for crop abiotic stresses

- The main sources of abiotic stress are drought (lack of water), heat, cold, and deficiency of nutrients (e.g., N, P, and K).
- Plant responses to abiotic stresses are often very similar to the responses to biotic stress, e.g. yellowing and browning of leaves, leaf loss, slowed growth, and reduced crop yield.

Measurable properties, accuracy and practicality

- The figure shows some of the specific absorption coefficients of pigments and other main optically active leaf ingredients.



Measurable properties, accuracy and practicality

- Most studies deal with the measurement of chlorophyll, N, or water content in plants.
- Chlorophyll absorption dominates the reflectance signal of leaves in the VIS section of the spectrum.
- Many methods for deriving plant traits from spectral data have been established.

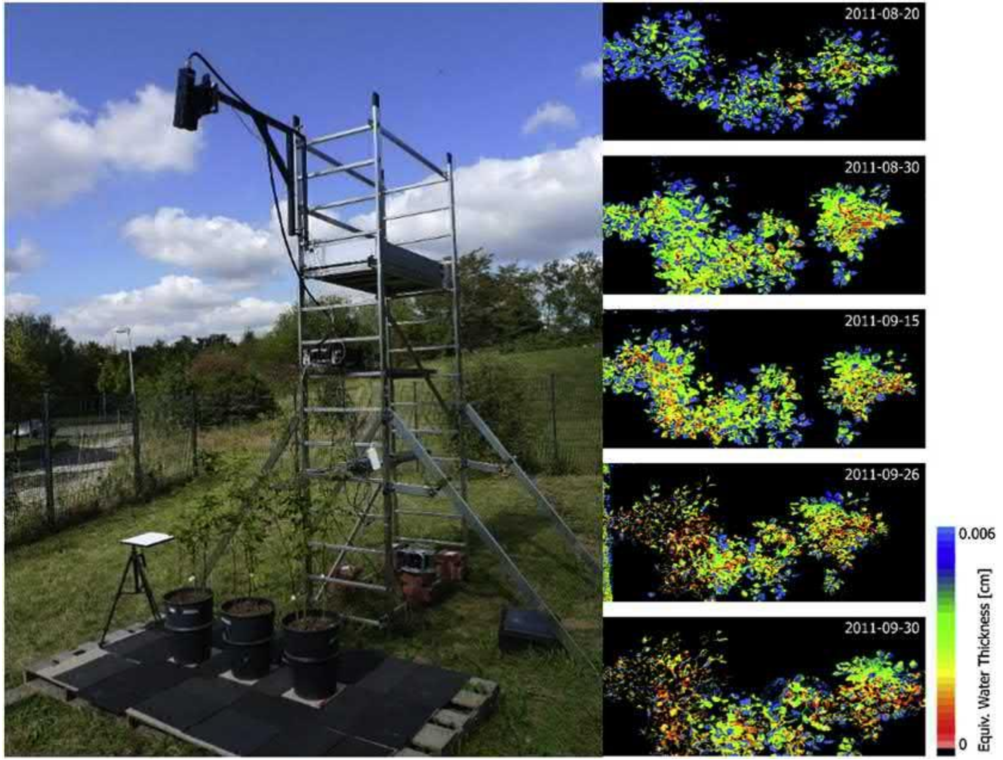
Measurements of LCC, LAI, chlorophyll, and water content

- Buddenbaum et al. (2012, 2015b) used two hyperspectral cameras attached to a rotation stage on a 3.8 m high platform to map chlorophyll and water content of beech seedlings.
  - Results showed that, as expected, soil water content decreased first, followed by leaf water content and, finally, LCC.
- Danner et al. (2017) selected two winter wheat fields in the North of Munich, Germany, for weekly measurements in 2014 and 2015.
  - Nonimaging spectroscopy measurements were recorded in nadir view and with zenith angles of 30 degrees.

Case studies

Left: Hyperspectral visible and near-infrared (VIS-NIR) camera on a rotation stage attached to a platform.

Right: Very high-resolution maps of leaf water content during drought-stress experiment over 5 weeks.



Proximal soil sensors

- Traditionally, soil conditions of agricultural fields are characterized by a limited number of samples being pooled into one 'representative' sample.
- There are two main technologies for proximal soil sensing.
  - The former relies mainly on the active creation of an electromagnetic (EM) field.
  - The latter relies on the transmission of an EM pulse into the soil and recording the reflection, such as with ground-penetrating radar.

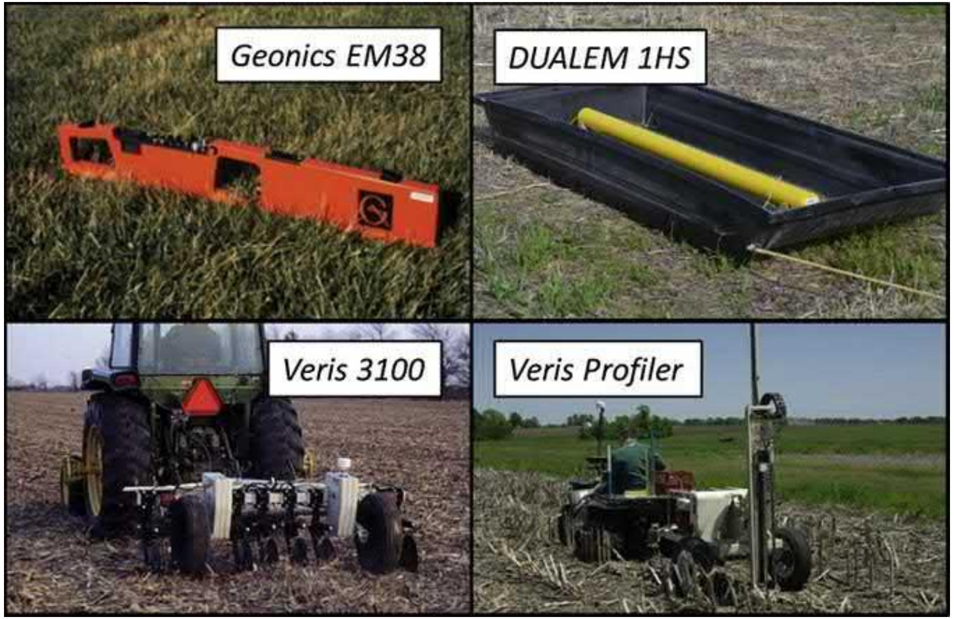
Geophysical methods applied to agriculture

Soil electrical conductivity

- Electrical conductivity (ECa) measurements of bulk soil were first investigated for their potential to assess salinity.
- Current technology for ECa sensing can be classified into three categories: EMI, galvanic coupled resistivity (GCR), and capacitively coupled resistivities (CCR).

Examples – EC_a instruments

Instruments employing the EMI approach



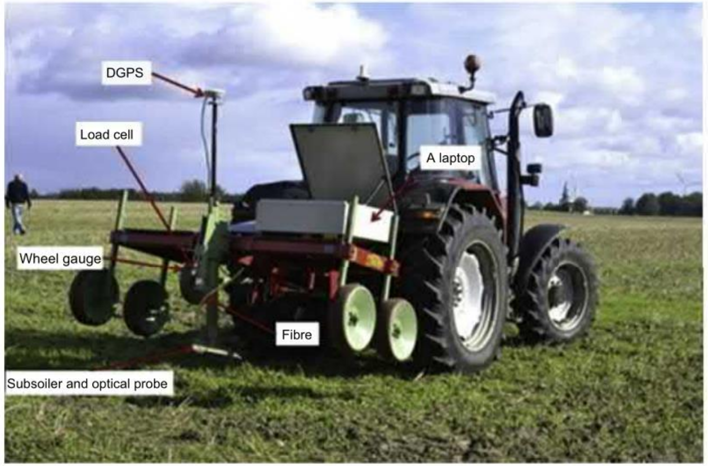
Soil electrical conductivity

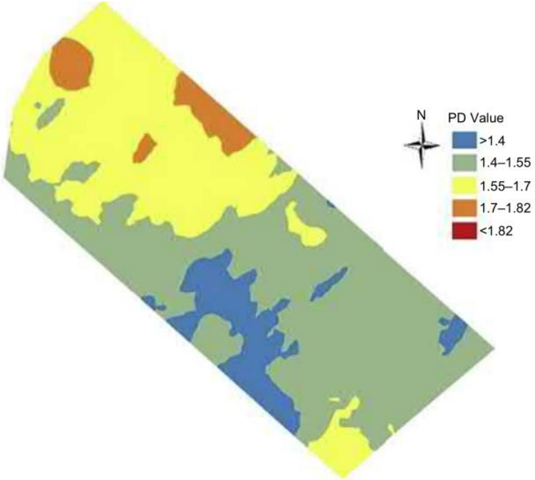
- Electrochemical decomposition index (ECa) measures the number of soil physical properties. Factors that influence ECa include soil salinity, clay content, and mineralogy.
- Soil ECa integrates texture and moisture availability, two characteristics that both vary over the landscape and also affect productivity.
  - It has been used to map soil physical, chemical, and biological properties related to yield and ecological potential.
- Soil ECa sensing is the most widely used proximal sensing technology.
- Soil ECa estimates were of variable accuracy, while the best estimates were generally obtained for CEC, clay, and silt.

Physical methods for sensing soil

- Soil compaction caused by wheel traffic of large agricultural machinery and/or tillage operations.
- Compaction can have deleterious effects on crop growing conditions and the environment.
- The first step to remediate soil compaction is to measure key parameters closely or directly associated with compaction.

Case study





Online soil sensor (left) and packing density (PD) map (right). The three PD classes on the map have been merged into three tillage zones as described in the text.

Electrochemical sensors

- Electrochemical sensing for soil analysis is based on the use of an ion-selective electrode and a field-effect transistor.
- The measurement is a direct one, unlike spectroscopic estimates of soil chemistry.
- Sensors can suffer from degraded performance over time due to ambient environmental conditions. Poor soil-electrode contact is a concern for in-soil sensors.

Electrochemical sensors

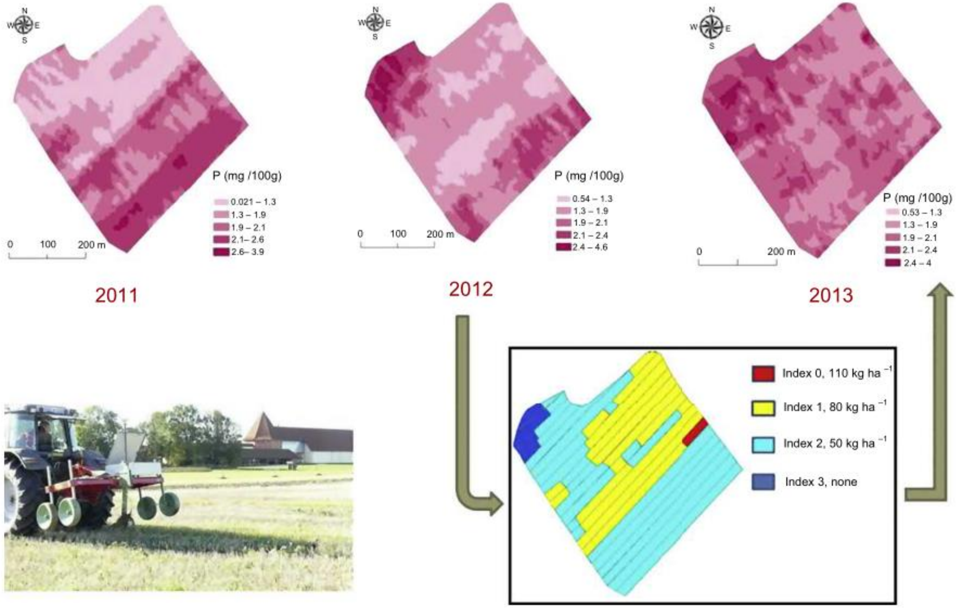
- Online real-time sensors present an attractive alternative to manual and/or laboratory methods.
- Sensors could provide measurements at a high spatial density and relatively low cost.
  - This could lead to greater overall accuracy in mapping soil variability than conventional lab methods.
- Spectroscopic sensing in the VIS, NIR, and MIR ranges generally measures soil nutrients indirectly.
  - This approach has been successful for pH and available P and K, although not mineral N.

Optical sensors

- Diffuse reflectance methods are fast, cost-effective, non-destructive, and environmentally friendly. They provide spectra that are highly characteristic of the soil type and composition.
- VIS-NIR spectroscopy is widely adapted to determine basic soil properties such as OM, clay minerals, texture, nutrients, as well as heavy metals and contaminants.
- Data mining techniques such as machine learning can handle both linearity and nonlinearity in the dataset.
- Field spectroscopy has more emphasized potential applications in PA. The most successful measurement is reported for organic and total forms.

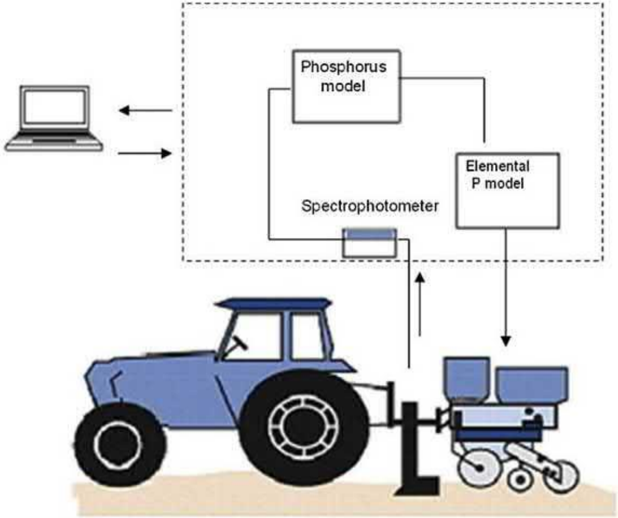
Optical sensors - Case studies

Illustration of site-specific P2O5 management based on measurement of extractable phosphorous (P) with online visible and near-infrared (VIS-NIR) spectroscopy sensor.



Optical sensors - Case studies

Illustration of sensor-based variable rate P2O5 fertilization based on measurement of available phosphorous (P) with online visible and near-infrared (VIS-NIR) spectroscopy sensor.



X-ray fluorescence (XRF) spectroscopy

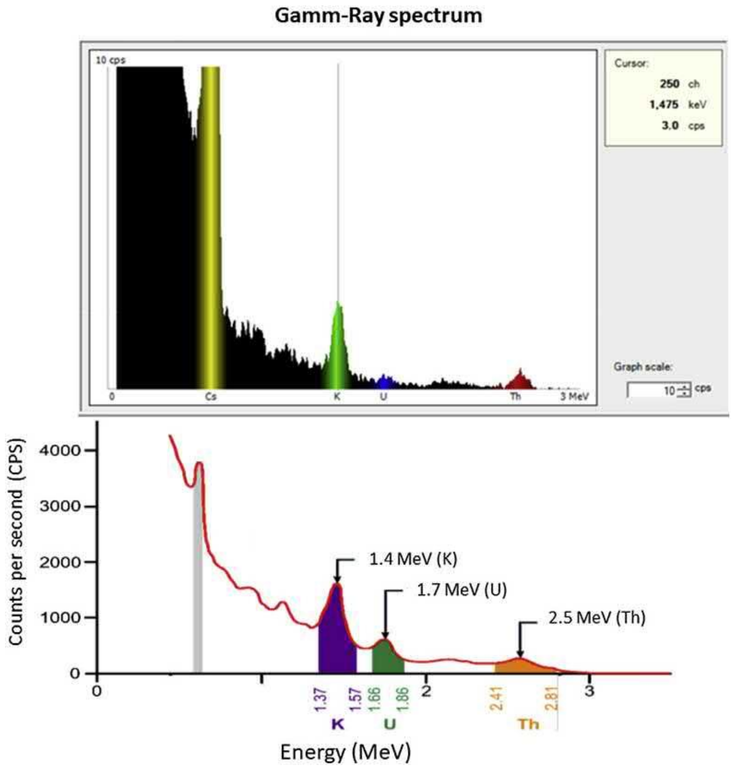
- XRF has many advantages as it is fast, non-destructive, and portable, which is essential for in situ measurement.
  - It has been used intensively for elemental analysis including contaminants in soils.
- XRF spectra can be used to develop customer-built calibration models, using multivariate analysis or machine learning tools.
- Portable XRF (PXRF) is a promising tool for rapid measurement of soil texture fractions.
- Zhu et al. (2011) investigated the feasibility of predicting soil clay, silt, and sand contents from PXRF data.

Gamma ray spectroscopy

- Gamma-ray spectroscopy measures gamma radiation emitted from the natural decay of radioactive isotopes.
- Information about mineralogy, weathering, and chemical properties of soil can be obtained.
- Gamma-ray spectroscopy can potentially be used to map available plant K in soils.
- Other researchers have evaluated the potential of gamma rays for the measurement of OC and pH using ground-based gamma-ray spectrometry.

Gamma-ray spectroscopy

- A decision tree classifier was used to predict soil types and yield data from the various combinations of geophysical and terrain attributes.
- Castrignanò et al. integrated multisensor data of a gamma-ray, ECa measured with EM38 and EM31, and RTK GPS.
- The gamma-ray is a useful tool for the prediction and mapping of soil texture.



Session Q&A