D2.2 Specialized training program on the use of sensor-based technology, biofertilisers & precision agriculture techniques

[VERSION 0.2]

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Technical References

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Executive Summary

This document is an integral part of the activities described in the Description of Action (DoA) of the project SOILdarity, which has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 952051. Deliverable 2.2 provides a description of the programme of two specialized training courses on proximal soil sensor technology, and biofertilizers use in precision agriculture. The aim is to provide the necessary knowledge and tools to increase key performance indicators and research outputs of FC.ID and CIÊNCIAS in the related topics.

The training programme will focus on theoretical & practical sessions on proximal soil sensing technologies used in precision agriculture for soil fertility measurement and management. The related courses will also link the use of precision agriculture solutions (e.g., sensing, mapping and variable rate applications) and biofertilizers as alternatives to current solutions of uniform rate fertilisation of chemical fertilisers. The training module will take place in Feb-April 2022 in two sessions. It is planned to have one-week course on the use of electromagnetic induction (EMI) in combination with soil sampling for management zone delineation and creation of variable rate fertilisation recommendation. In addition, 1-week course is planned on introducing optical sensor and Multi-sensor data-fusion, for management zone delineation and the creation of variable rate fertilisation including those of chemical and bio-fertilisers.

Inside the WP2, the D2.2 (Specialized training programme on the use of sensor-based technology, biofertilisers and precision agriculture techniques) is developed in parallel with D2.1 (Specialized training programme on water management, plant-soil interactions, and alternative fertilizers) and integrated with the activities included in the present program. The document provides a detailed description of the D2.2, which is consider as an integral part of WP2. In the following sections, the programme of the courses will be described, covering different aspects such as the training objectives, their location, planning, activities to carry out, and target audience.

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Spelling Guidelines

Standardised British spelling should be used in the document. Generic terms are spelled in lower case, specific terms and proper names are spelled with initial capitals.

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1. Deliverable 2.2

1.1 Aim

The objective of this WP is to increase knowledge and develop research capacity of the scientific staff within FC.ID and CIÊNCIAS on:
(1) The use of advanced proximal soil sensing tools for optimising the variable rate application of biofertilisers as alternative source of nutrients compared to chemical fertilisers that are applied by majority of farmers today. Methods include sensor-based analysis of soil physical and chemical characteristics using proximal sensing technologies, namely, electrical magnetic induction with EM38 MK2, gamma ray, electrochemical, and visible and near infrared spectroscopy technologies. Other knowledge include geostatistical modelling and mapping and develop recommendations for variable rate fertilisation. (2) Research skills, innovation and leadership to improve research excellence, innovation capacity and scientific quality of the institution concerned in the related topics under D2.2.

1.2 Roles and responsibilities within the Consortium

SOILdarity consortium partners FCID and MIGAL and CIÊNCIAS will coordinate with UGENT during the training program and EUKNOW will support locally, in order to manage the programs' implementation (identification of students available for trainings, selection of participants, venue organization).

1.3 Target Participants

About 20 attendees from FC.ID or CIÊNCIAS will take part in the activities, notably, researchers, Early stage Researchers (ESRs) and students who have an adequate background and knowledge of the topics addressed by this deliverable. These crosscutting initiatives could also be made open to other stakeholders such as government entities, public authorities, other educational institutions, professionals etc. They will definitely learn many new things in the field of precision agriculture specifically in soil quality measurements using advanced proximal soil sensing, related modelling and mapping tools.

1.4 Expected Outcome of D2.2

- Students will understand the basic concepts of proximal soil sensing techniques, and VR techniques and able to conduct field experiment to acquire high sampling resolution raw data using vis-NIR and EMI sensing technologies.
- Students will be able to acquire field data on the key soil fertility attributes, using with multi-sensor platform available from UGent, or the EMI platform available at MIGAL.
- Students will be able to perform multivariate data analysis techniques on collected data for soil fertility prediction.

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- The students will be able to map the spatial variability in key soil fertility attributes provided at high density sampling > 500 points per hectare
- The results obtained with D2.2 will be further used for D3.2 for the students/attendees to be trained to write a scientific publication.

2. Detailed Plan for D2.2

2.1. Course Structure

D2.2 plan composed of two kinds of training modules:

- Theoretical & practical assessments on proximal sensing technologies for soil fertility (Module1).
- Combining biofertiliser with precision agriculture technologies (Module2).

2.2. Location, Delivery Date & Duration

According to the DoA, workshops should be held in Lisbon, Portugal in Feb-April/2022, designed for 2 weeks.

2.3. Training Mode

Module1: Schedule via Zoom meetings, just in case the limitations related to the spread of the COVID-19 should continue or UGENT and MIGAL teams will travel to Portugal (subject to the project budget) for theoretical lectures and field experiments/demos.
Module2: UGENT and MIGAL team will travel to Portugal for theoretical lectures and field experiments/demos.

2.4. Supporting Material

The creation of specific supporting materials also corresponds to an important part of the preparation process of the named courses. These materials will be essential to create, discuss or communicate new ideas. Supporting materials include Digital tools such as PowerPoint presentation, videos, web-based tools, etc.

2.5. Experts for Theoretical and Practical Sessions

Prof. Iggy Litaor, (M), received his PhD in geochemistry from the University of Colorado in 1986. He has been involved in research of soil, water and snow dynamics in the alpine zone of Colorado Front Range since 1981 to present as part of the CULTER program. Between 1990 and 1996, he studied the fate and transport of radionuclides (Pu, Am & U) around a nuclear facility and their potential influence on residential areas around the site. Since 1996, Prof. Litaor

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is conducting research on the hydro-geochemistry of P in wetlands and in altered wetland soils. The studies encompass the assessment of the mineralogy, sorption-desorption mechanisms, fate and transport in highly fractured peat environs, impact of various land use and land use change on P transport to waterways. More recently Prof Litaor developed a new design of aerated cells/constructed wetlands to treat organic-rich wastewaters such as winery, dairy and olive mills wastewaters. Most recently, his research deals with optimal soil sampling using Pareto optimization approach. His current research projects are: (1) testing the feasibility of P capture, recycling and utilization for sustainable agriculture and a clean environment using Al/Organic Composite water treatment residuals (Al/O-WTR) and Fe-desalinization treatment residue (Fe/O-DTR). (2) Exploring the possibility of co-addition of compost and zeolites for improvement of soil quality and fertility by increasing K availability. (3) Exploring the possibility of co-addition of compost and zeolites for improvement of soil quality in agro- forested setting. (4) Development of integrated solution systems for precision irrigation and fertilizer management.

Prof Cristina Cruz, (F), Dr. Cristina Cruz has a background in plant physiology and works along with the plant Soil Ecology group of the cE3c. Cristina is responsible for the implementation of three national and one international projects, supervisor of four PhD students and advisor of six Post Docs. She is involved in the maintenance of a long-term ecological to monitor the response of Mediterranean ecosystems to changes in resource availability over time and space. Understanding the role of soil ecology on plant productivity and sustainability of eco- and agro-systems and in engineering the rhizosphere of crop plants in order to obtain plants tolerant of higher stresses, with increased nutrient use efficiencies and nutritional value.

Prof. Abdul M. Mouazen, (M), is a full professor in precision soil and crop management and a group leader of Precision SCoRing Group in Ghent University. He holds a PhD degree in numerical modelling of soil-tillage tools interaction and has a background in the application of engineering principles to soil and water management with specific application in soil dynamics, tillage, traction, compaction, mechanical weeding, soil remediation and management. He teaches in topics related to proximal soil sensing for precision agricultural applications at UGent. This includes two course, namely, Precision Agriculture and Environmental Soil Sensing. He is a member of Global Proximal Soil Sensing Committee, since established. He has implemented Vis-NIR and MIR spectroscopy for analysis of soil, manure, honey, milk, cheese, mandarin, and other food and environmental materials. His experience in vis-NIR spectroscopy and chemometric tools enabled him to develop one of three internationally patented on-line measurement systems of soil properties (Mouazen, 2006). He has coordinated two major European projects (FarmingTruth funded by Euoropean Space Agency & FarmFUSE, funded by EU-FP7 under IRA-NET, ICT-AGRI), and has been a partner in several other national and international projects. He is also the scientific coordinator of H2020 SIEUSOIL project (2019-2022). He also coordinating wo new ERA-NET research projects on topics related to D2.2: 1) ADDFerti - A Data-Driven Platform for Site-Specific Fertigation (funded by the ICT-AGRI-FOOD), and 2) POSHMyCo - Potential of selective harvest based on mycotoxins content assessment in cereal crops (funded by the ICT-AGRI-FOOD). Prof. Abdul is an Associate Editor of Soil & Tillage Research, Soil Research, Biosystems Engineering, Remote sensing and Soil Systems, and has some 185 indexed contributions in Web of Science Science (h index = 40).

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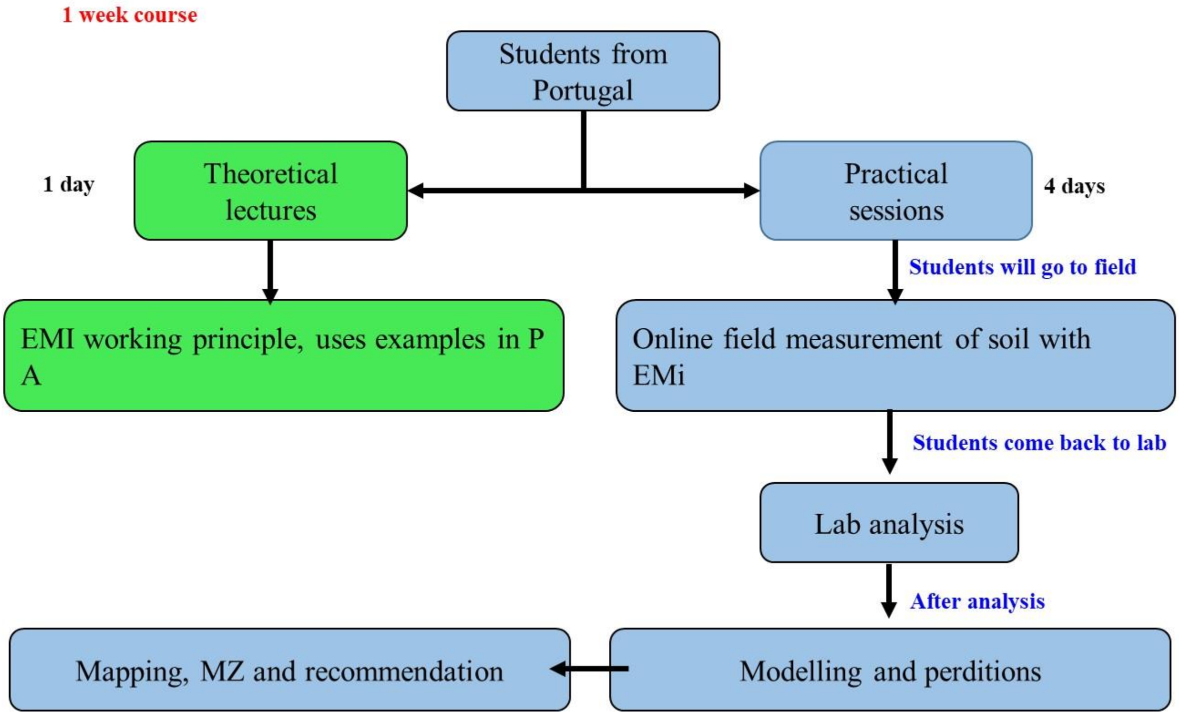
Abdul has supervised several postgraduate students working on vis-NIR and MIR spectroscopy applications, with majority working on sensing and control for precision agriculture applications.

Dr. Lalit M. Kandpal, (M), is a Postdoc Researcher in Precision SCoRing Group in Ghent University. Lalit Mohan Kandpal received his B.S. degree in Radiology from Government Medical College Haldwani, India in 2010. His MS-PhD from Chungnam National University Daejeon, South Korea in 2017. He was working as a Postdoc and Research Professor at the Chungnam National University from 2017 to 2019 where he developed his skills in spectroscopy/imaging and chemometric modelling for quality analysis of agro-food and pharmaceutical products. His field of interest include advance sensing technologies and their applications, data mining, data processing and project management.

2.6. Proximal soil sensing technologies for soil fertility assessment (Module 1)

The Module 1 will consist of two main submodule: 1) training on geophysical methods, whose plan is shown in Figure 1 a, and 2) training of optical, electrochemical, gamma ray and multi-sensor data fusion methods, whose plan is shown in Figure 1 b.



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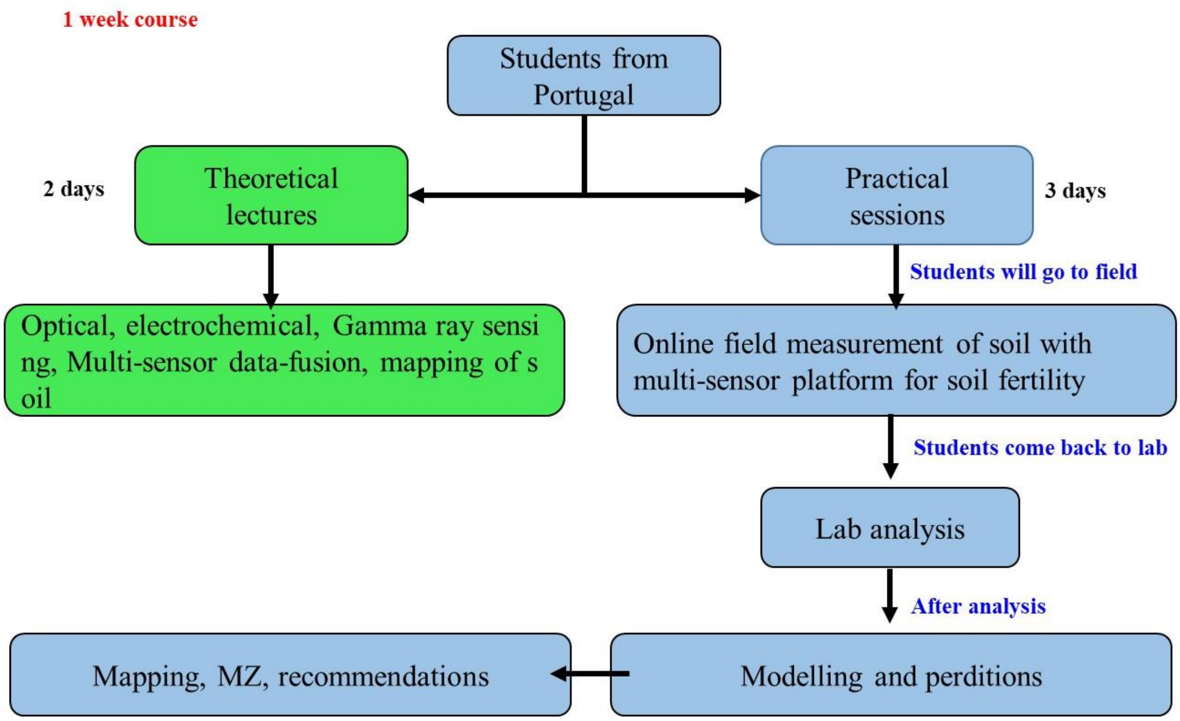

Figure 1: Planning of the theoretical and practical sessions of the proximal soil sensing course for A) geophysical methods and B) optical, electrochemical, gamma ray and multi-sensor data fusion methods.

2.6.1. Detail plan for theoretical session

One or more aforementioned experts from UGENT & MIGAL will deliver each particular course. This course will open with general introduction on proximal soil sensing techniques and related work in soil quality monitoring and mapping. Proximal soil sensing has become a multidisciplinary area of study that aims to develop field-based techniques for collecting information on the soil from close by, or within, the soil. This course will provide the understanding the working principle and case study of various proximal soil sensing techniques and discusses the state of art in soil sensing techniques. More specifically, the course topics covered in the training program are briefly outlined below:

- **Lecture on Geophysical sensing methods (by Prof Iggy Litaor).** Geophysical methods exploit contrasts in physical properties (locate soil, lithologic and stratigraphic boundaries and characterize soil patters and features). Examples of the physical properties include dielectric permittivity, apparent electrical conductivity (ECa) or resistivity, and magnetic susceptibility. The lecture will focus on:
  - Introduction to Geophysical techniques
  - Basic principles of geophysical soil mapping
  - Electromagnetic induction (EMI) to measure ECa: The EMI sensors are based on Faraday's law used in physics. The EMI device is composed of a transmitter coil and a receiver coil installed on both ends of a nonconductive bar. The transmitter coil at or above the ground surface is energized with an alternating

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current, creating a primary, time-varying magnetic field in the soil (Figure 2). This magnetic field induces small eddy currents in the soil, while the soil matrix produces a weak secondary magnetic field. The receiver coil responds to both the primary and weak secondary magnetic fields. The secondary magnetic field is, in general, a complicated function of the inter-coil spacing, operating frequency, and ground conductivity. As soil conductivity is not homogeneous, the EMI device measures electrical conductivity of the total volume of soil contributing to the signal. Soil conductivity is, therefore, called apparent or bulk soil electrical conductivity. Operating at low induction numbers, the ratio between the primary magnetic field and secondary magnetic field is a linear function of bulk or EC_a.

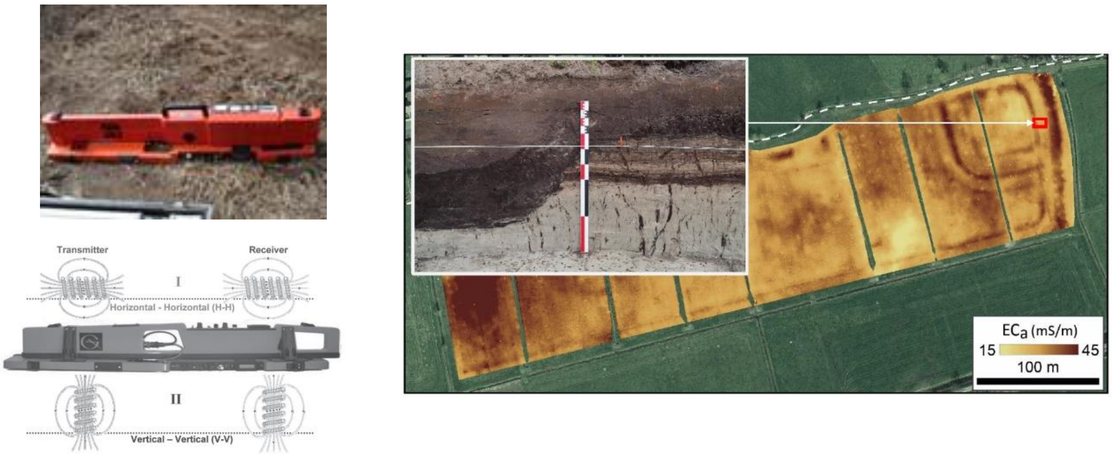

Figure 2: Example of electrical soil variation mapped with an electromagnetic induction (EMI) instrument

- Electrical resistivity/conductivity. Resistance describes how strongly a medium (or an object) resists current flow. Electrical resistivity (ER) sensing is a contact-based soil sensing technique which introduces an electrical current into the soil through the contact electrodes, and the difference in current flow potential is measured at potential electrodes that are placed in the vicinity of the current flow (Figure 3). The ER technique requires good contact between the soil and four electrodes. In stony or dry soil, there may be chance of improper contact between the soil and electrodes. This is a drawback of the technique, which might give less reliable measurements as compared to the EMI technique. ER methods introduce an electrical current into the soil through current electrodes at the soil surface and the difference in current flow potential is measured at potential electrodes that are placed in the vicinity of the current flow. This method measures bulk soil resistivity and the reciprocal of which is EC_a.

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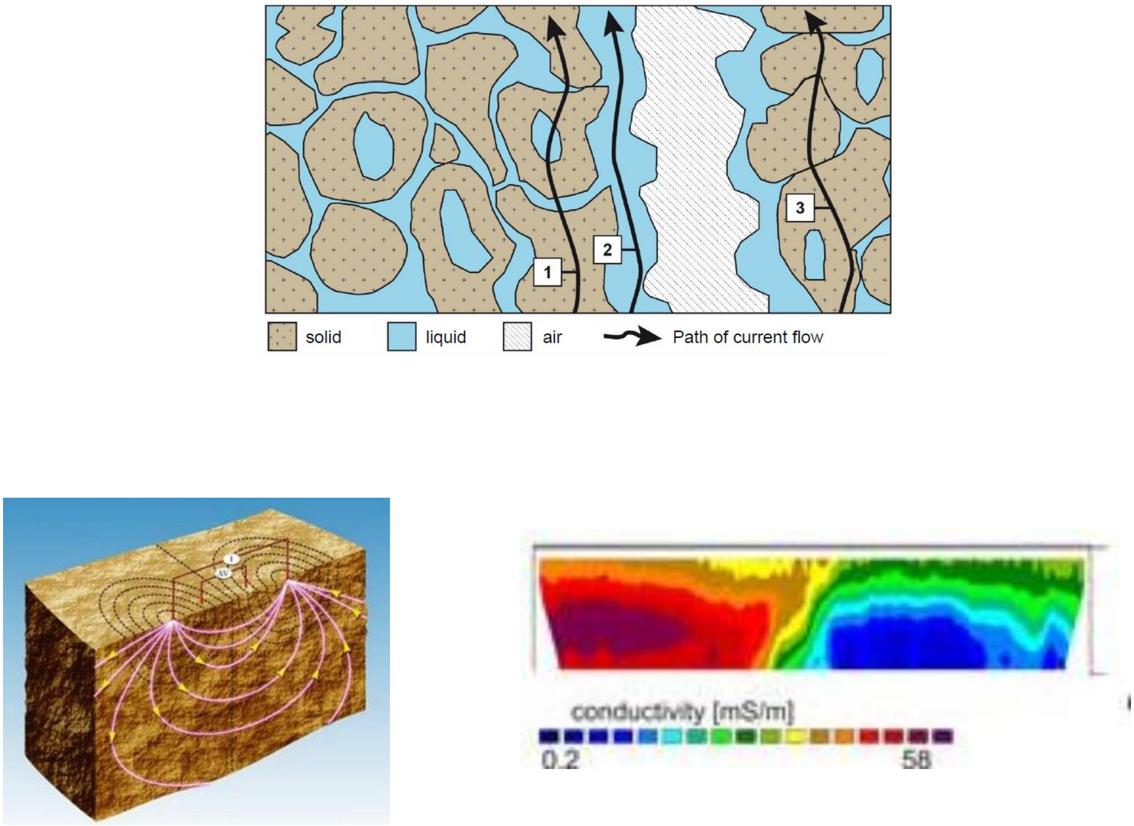

Figure 3: Electrical resistivity in soils

- Ground penetrating radar (GPR). Geophysical method that uses radar pulses to collect data from beneath the subsurface. Ground penetrating radar (GPR) is basically a geophysical technique which is particularly appropriate to image the soil in two or three dimensions with a high spatial resolution up to a depth of several meters. The working principle of GPR is similar to reflection seismic and sonar techniques. Electromagnetic (EM) waves are transmitted towards the soil and from the reflections of this wave properties of the soil can be extracted (Figure 4). GPR systems work in a frequency range of 10-5000 MHz (e.g. VHF-UHF). The main characteristics of a GPR system are its operating frequency (centre frequency), resolution, and depth of penetration. GPR resolution is the ability of the system to distinguish two signals that are close to each other in time. Usually, the resolution of a GPR increases with increasing operating frequency. As the penetration depth reduces with increasing frequency, the choice of an operating frequency is always a trade-off between resolution and penetration depth, as higher frequencies permit higher resolution but lower penetration depth. Propagation of the EM waves into the soil is mainly governed by soil dielectric permittivity (ε) (determining wave velocity), electrical conductivity (σ) (determining wave attenuation), magnetic permeability (μ) (determining wave velocity and affecting wave attenuation), and their spatial distribution.

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Reflection of the EM wave is caused by soil layers having a different permittivity. Both the reflection and attenuation of the EM wave offer the opportunity to assess properties of the soil.

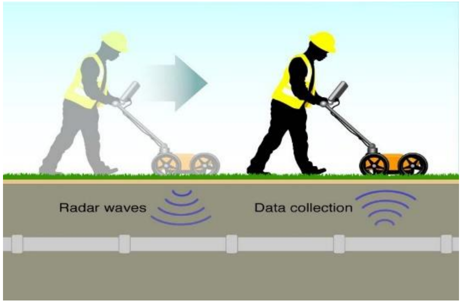

Figure 4: Ground penetrating radar (GPR)

- **Lecture on Optical techniques (by Prof Abdul M. Mouazen).** There are very wide range of optical sensors applied to determine the soil fertility attributes. Optical reflectance methods include the visible (vis), near infrared (NIR), and mid infrared (MIR) spectroscopy. The lectures under this sensing categories lecture will focus on:

    - Basic principle of optical spectroscopy. Spectroscopy is the study of interaction of matter and light (radiated energy). It can be used to explore relative composition of a material (i.e., organic and inorganic compounds in soil). This section will introduce working principle of optical spectroscopy and basic components used to construct spectroscopic instrument.

The EM energy travels in waves and spans a broad spectrum from long radio waves to very short gamma rays (Figure 5). The human eye can only detect a small portion of this spectrum called visible light. A radio detects a different portion of the spectrum, and an x-ray machine uses yet another portion. This lecture will discuss scientific instruments that uses different range of electromagnetic spectrum to study the soil characteristics. Since soils are a mixture of mineral and organic matter with a physical structure composed of macroscopic aggregates of particles and porous spaces, which may contain water or air, they are a highly light absorbing and scattering medium. Once a soil medium is subjected to a light source, part of the light is absorbed, and part diffusely reflected out of the soil (Figure 6). The final shape of soil spectra either in the vis-NIR or MIR (Figure 6) is a reflection of both the light scattering and absorption phenomena that differs due to the sample physical and chemical characteristics, respectively.

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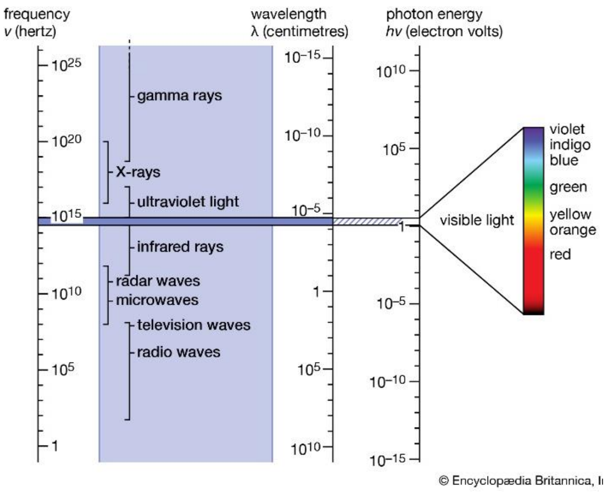

Figure 5: The Electromagnetic spectrum, highlighting the visible, and infrared (near infrared and mid infrared) frequencies

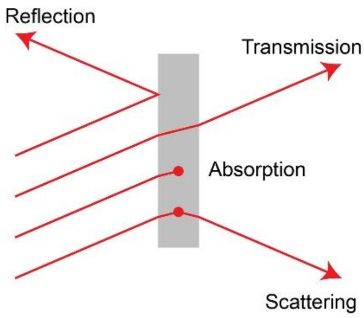

Figure 6: Different types of light interaction with an object

The working principle of VIS-NIR absorption stems from the activating of chemical bonds by irradiating mineral mixtures thereby creating resonance vibration of different modes, e.g., bending or stretching. Vibrations result in light absorption, in different levels, having a particular power quantum related towards the distinction between two energy levels. Since the energy quantum is actually associated with frequency, the resulting absorption features of the spectrum curve can be used for analytical purposes (Stenberg et al., 2010). In the VIS range (400–780 nm), absorption bands related to soil colour are due to electron excitations. This is an important feature, as colour can be indirectly linked with key soil properties such as organic matter (OM), iron (and perhaps P), and moisture content MC. Within the NIR range (780 – 2500 nm), overtones of OH and overtones and combinations of C-H + C-H, C-H + C-C, OH+ minerals, and N-H of fundamental vibrations (e.g., C–H, N–H, O–H, C–O, Si–O) that occur in the MIR spectral range (2500–25000 nm or wave number of 4000–400 cm^{-1}) are the major spectral features essential for the detection and quantification of key soil properties having direct spectral responses [e.g., MC, OM, clay minerals, and total nitrogen (TN)] (Figure 7). These properties can be predicted with VIS-NIR spectroscopy with appreciable accuracy, compared to properties with indirect spectral responses (e.g., P, K, Mg, Ca, Na,

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CEC, pH) that are potentially predictable through covariation with properties having direct spectral responses in the VIS-NIR spectral range (Stenberg et al., 2010). The NIR overtones and combinations are of broad bands that overlap and are 10-100 times weaker, compared with MIR fundamental vibrations-based spectral features, which are more resolved, permitting the structure of a sample to be better elucidated (Mouazen et al., 2019).

- Types of optical instrument used in soil analysis**.** This lecture will focus on the vis, NIR and MIR spectroscopy which are characterized as rapid, nondestructive, reproducible, and cost-effective analytical methods.

The higher energy of NIR radiation and the relatively low absorptivity of water position NIR spectroscopy as a better technique when wet soils and sediments samples are analysed compared with MIR spectroscop. However, MIR has advantages for soil analysis due to its sensitivity to both the organic and inorganic constituents, thanks to fundamental vibrations of molecules. Therefore, MIR can provide extensive and valuable information about the chemical and physical properties of the sample components. Despite the fundamental vibrations in the MIR, VIS-NIR spectroscopy is widely adapted to determine basic soil composition, particularly OM, clay minerals, texture, nutrients, as well as heavy metals and hydrocarbons contaminants. This is particularly true for *in situ* and on-line applications and is attributed mainly to robustness, portability and the moderate effect of MC on VIS-NIR compared to MIR spectroscopy. However, one of the important limitations associated with VIS-NIR is that the spectra are complex and nonspecific, due to the overlapping absorptions among overtones and combinations resulted from their broad bands that affect the prediction accuracy of the models derived. This lecture will discuss the potential of these spectroscopy techniques for in situ and on-line measurement of key soil fertility attributes.

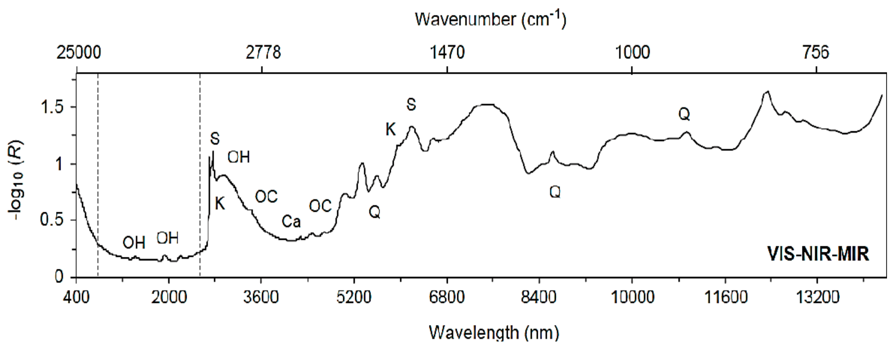

Figure 7: Soil dominant components and absorption peaks for the Vis-NIR-MIR region (Martín-López, 2017)

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- Field spectroscopy & case studies to measure and map key soil fertility attributes. The use of spectroscopy for scanning fresh soil samples (distributed and non-distributed), either in the laboratory or *in situ* (portable and on-line) will be discussed. Figure6 8-11 show the material to be used for present potential of field spectroscopy to measure and maps key soil properties.

Figure 8: Field (in situ) scanning

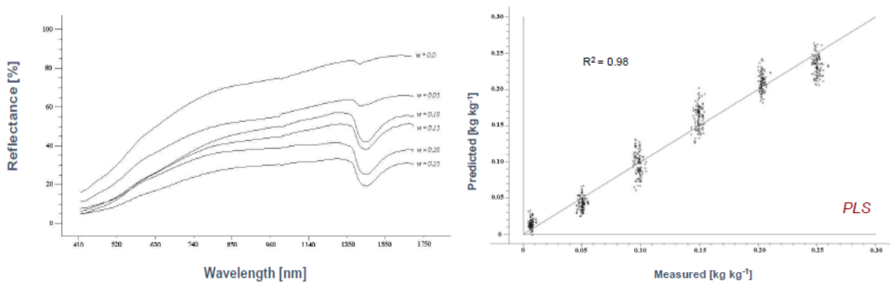
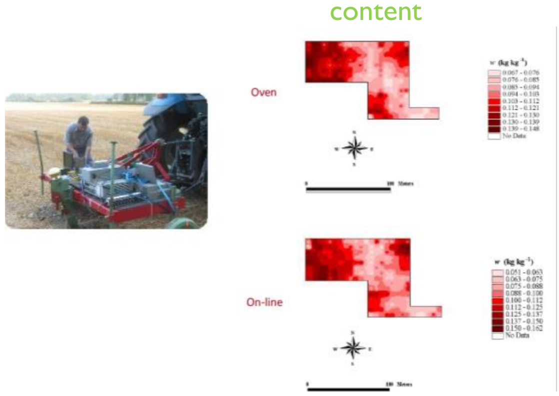


Figure 9: VIS-NIR spectra characteristics and modelling for the prediction of moisture content



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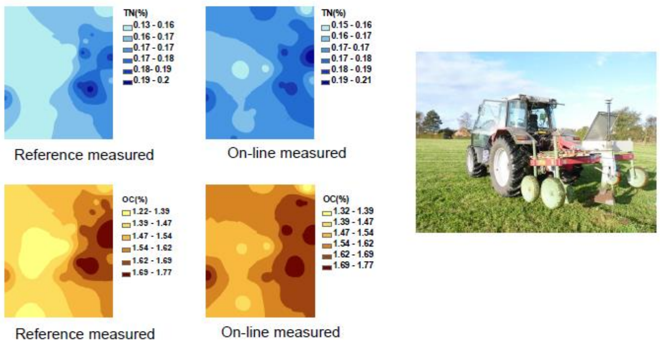

Figure 10: On-line (tractor based) scanning of field for on-line prediction and mapping of moisture mapping (A) Organic carbon (OC) and total nitrogen (TN) (B)

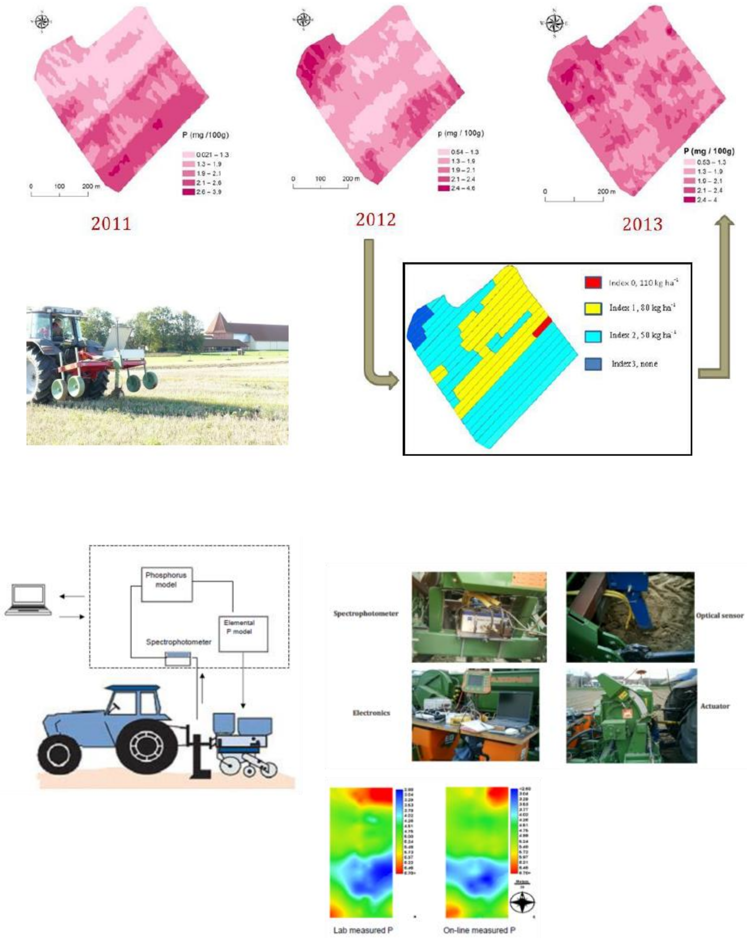

Figure 11: Sensor based site-specific P Fertilisation based on on-line measurement of soil phosphorous

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- Factors affecting field spectroscopy. The lecture will discuss advantages and challenges in field spectroscopy measurement and factors affecting field spectroscopy such as, moisture content, roots, stones, plant residue, ambient light, variation in soil-to-sensor distance and angle, surface roughness, etc. Also, we will discuss about solution to minimize affecting factors.

► **Lecture on Electrochemical technique (by Prof Abdul M. Mouazen).** Electrochemical technique used to measure available nutrients and pH in the soil. It measures a voltage difference (electrical potential) between sensing and reference parts (electrodes) of the system, which is directly related to the concentration and the activity of specific ions such as, H+, K+, Na+, etc. This lecture will focus on below topics:

- Basic concept of electrochemical sensing. Electrochemical sensors are the most versatile and highly developed chemical sensors. They are divided into Potentiometric (measure voltage), Amperometric (measure current) and conductometic (measure conductivity). In all these sensors special electrodes are used, and these are ion specific.

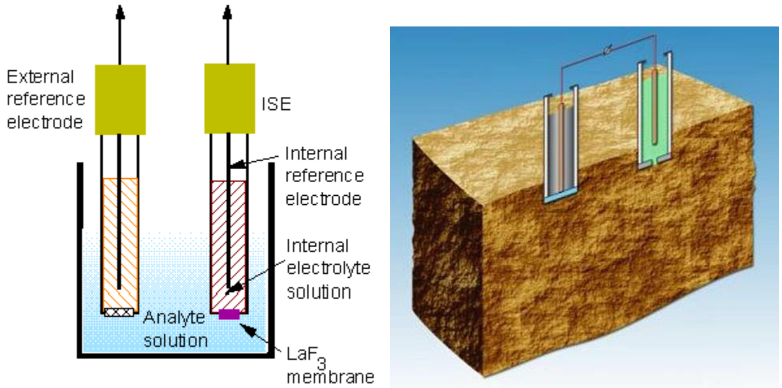

Figure 12: Ion selective electrodes (ISE)

- Ion-selective electrode (ISE). ISE are potentiometric sensors that use ion-selective membranes to measure the concentration of the target sample (Figure 12). When submerged in the solution to be analyzed, an electromotive force is generated at the sensing surface proportional to the log of the ion activity. The electromotive force can then be measured using a suitable reference system (e.g., a reference electrode). ISEs selective for many useful soil nutrients (nitrate, sodium, potassium, calcium).

- Ion-sensitive field effect transistor (ISFET). ISFETs combine ISE technology with that of the field effect transistor (FET). The construction of the ISFET is as

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for the standard FET; however, the gate is replaced with a separate electrode (in contact with the analysis electrolyte) and the exposed insulating oxide (commonly SiO2 but also Al2O3, Ta2O5) is also left in contact with the electrolyte being analyzed (Figure 13). The charge developed on the oxide surface (due to proton interaction) now controls the source–drain current of the FET, which is then indicative of the electrolyte. Key advantages of pH ISFETs over standard glass pH electrodes are small size, increased durability, fast response, and the ability to mass produce using microelectronic manufacturing techniques. They have been used for proximal sensing of soil pH and lime requirement. The lecture will discuss advantageous and disadvantageous of ISE in comparison with ISFET.

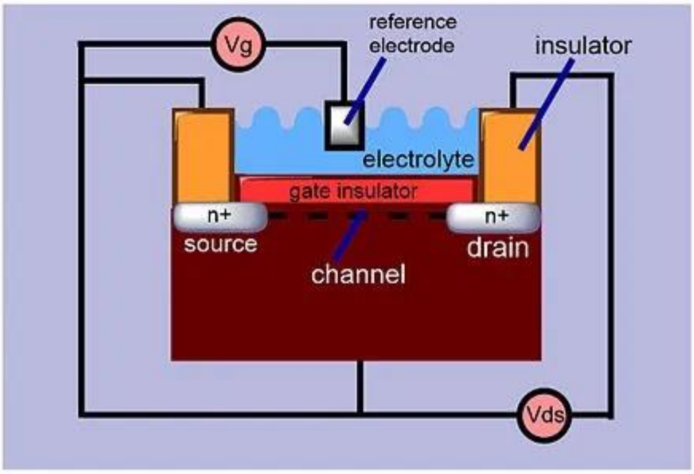

Figure 13: Ion-selective field effect transistor (ISFET)

In this lecture we plan to review case studies on the use of ISFET and ISE for the measurement and mapping of key soil attributes. Case studies at laboratory-controlled conditions, field stationary conditions and on-line conditions will be introduced. Students will learn about the potential of these electrochemical sensor technologies against those of the geophysical and optical methods discussed above in their ability to measure the available version of soil nutrients.

- **Lecture on Gamma ray sensing (by Prof Abdul M. Mouazen).** The lecture will also focus on:

  - Working principle of the Gamma ray sensing: Gamma sensor measures gamma radiation emitted from the natural decay of radioactive isotopes [e.g., potassium (K), uranium (U), and thorium (Th)] that are present in soils. Gamma-ray spectrometers typically measure 256-512 channels that comprise an energy spectrum ranging from 0 to 3 MeV. The energy bands around 1.4, 1.7 and 2.55 MeV correspond to the diagnostic energy peaks proportional to total potassium (K),

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uranium (U) and thorium (Th), respectively, which are due to the natural decay of these elements (Fig. 14). It provides the information about mineralogy, weathering, and chemical properties of soil (K) and soil texture.

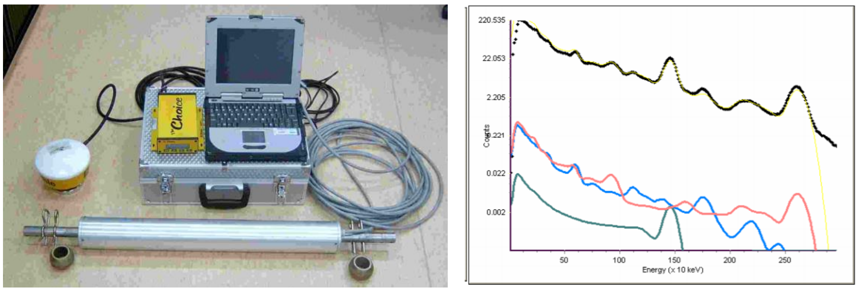
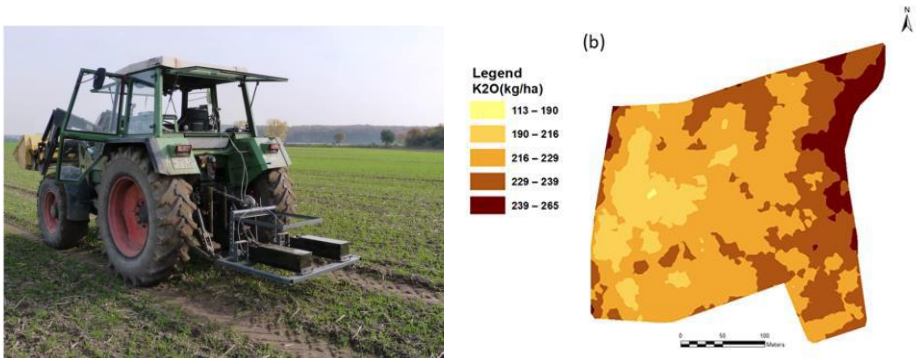
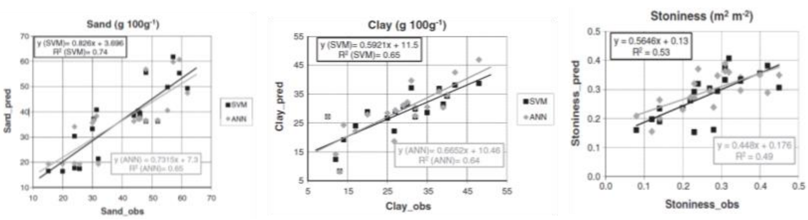


Figure 14: Gamma-ray sensor with measured spectrum. Soil spectrum (black dots) as compared to standard spectra of 40K (green), 238U (blue) and 233Th (red)

- Detectors types of passive gamma ray, their comparative advantageous and shortcomings.
- Application of Gamma ray for soil mentoring. Case studies of the use of on-line gamma ray system to measure texture, potassium and stoniness is the soil will be presented. These are the most relevant soil properties that gamma ray can potentially measure (Figure 15).



(A)



(B)

Figure 15: Case study on Gamma ray for available potassium (A) and texture and stoniness prediction (B)

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► **Lecture on Multi-sensor data fusion techniques (by Prof Abdul M. Mouazen).** This lecture will discuss about data and model fusion methods in precision agriculture. Soils are typically characterizing by high variability on all scales that can be monitored using different sensor systems. Each sensor offers an exclusive perspective on one aspect of a soil system that will change both temporally and spatially. Consequently, requiring a single sensor to perform more than one function in these circumstances is almost unfeasible. Data fusion is the combination of data from different sources to produce more rigorous data than could be obtained from a single system or sensor (see Figure 16). The lecture will focus on:

- Multi-sensor data fusion: Theoretical background and methods used in multi-sensor data fusion.

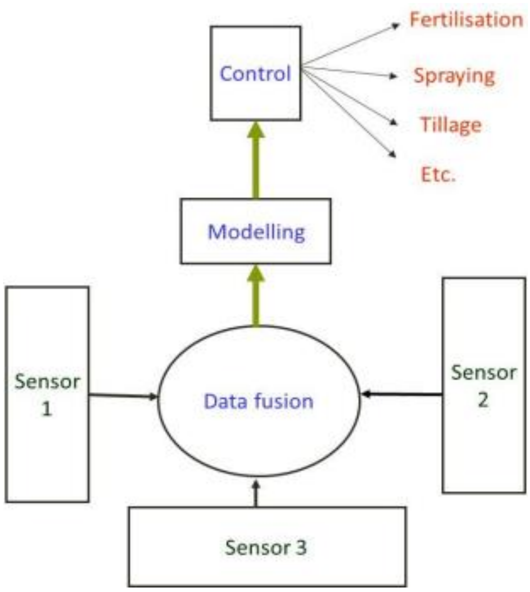

Figure 16: Multi-sensor data fusion in precision agriculture

- Proximal sensor data fusion: Data of different sensors are applied jointly into a single multivariate or machine learning method.
- Multi-model fusion: Models are combined to provide the optimal prediction of a key soil property.
- Case study based on multi-sensor data fusion. Case studies of multi-sensor data fusion for site specific fungicide application; site specific potato seeding; selective harvest, site specific manure application and site-specific N, P and K fertilization will be presented.

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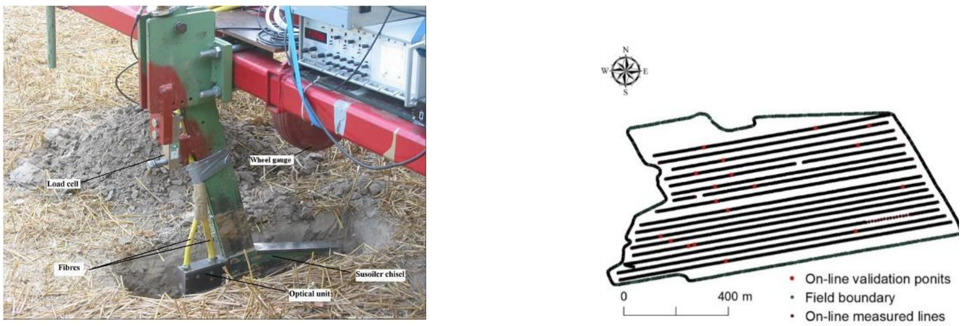
2.6.2. Detail plan for the practical sessions

UGENT team will provide practical sessions to the participants/students. This session will be based on field trips and practical exercises consist of field survey, soil sampling, sensor calibration, soil spectra collection, soil data analysis for fertility measurement, modelling and finally mapping. In this session, students will have a chance to implement their knowledge (taught during theoretical lectures) to conduct the practical experiments of soil fertility measurement. For this session, Portugal team will organize a a commercial/experimental field for data collection. The steps for practical assignments are briefly outlined below:

- **Demonstration of sensing technology of UGENT.** After theoretical lectures, UGENT team will present a demo about laboratory-based & field-based sensing platforms (shown in Figure 17 and Figure 18). The mode of demo will be in the form of pre-recorded video. From the video, participants/students will able to understand the actual components of the multi-sensor platform, soil-scanning technique with sensors, spectra collection and data analysis.

Figure 17: UGENT multi-sensor. (a) visible and near infrared (vis-NIR), (b) vis-NIR, (c) mid infrared (MIR), (d) hyperspectral camera, (e) x-ray fluorescence (XRF), and (f) Gamma ray



(A) (B)

Figure 18: UGENT online soil sensing platform (Mouazen, 2006), based on visible and near infrared (vis-NIR) spectroscopy (A). On-line measurement and Measured transects and position of sampling points (B)

- **Field survey.** The students will attend a field survey in a commercial field in

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Portugal and they will be trained by the UGENT experts for soil sample preparation, which involves collecting the soil samples (~100g per sample) of top soil (<50cm), bagging and labelling methods for spectral measurement.

- **Field measurement.** In the same commercial field of Portugal, participants will learn the UGent online soil sensing platform. The UGENT online sensing platform is composed of a subsoiler fitted to a frame that penetrates the soil to the require depth, it is attached to the three-point linkage tractor (Figure 18). The optical unit is attached to the backside of the subsoilar to measure the vis-NIR soil spectra in diffuse reflectance mode within the wave-range from 305~1700 nm. Students will learn/practice the use of online multi-sensor platform with and record the soil spectra (see Figure 19) for future modelling.

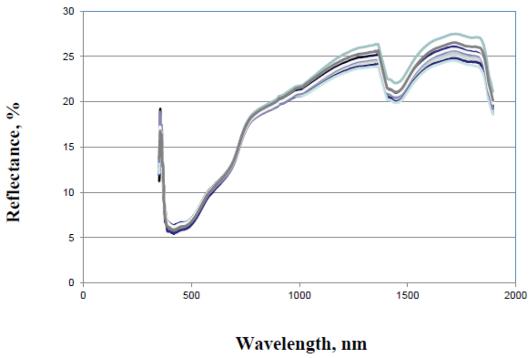

Figure 19: Example of on-line collected visible and near infrared (vis-NIR) soil spectra using the online multi-sensor platform of UGENT

- **Data analysis and modelling.** This course will discuss about concept of multivariate statistics used for the analysis of collected data with proximal soil sensors. It also includes spectra preprocessing and modelling methods such as machine learning techniques for of soil data. The lectures will focus on:

  - Spectra preprocessing to exclude noisy datasets: Spectral preprocessing is a specific step carry out before spectra modelling is carried out. During this step the noisy edges of spectral will trimmed out before it is subjected to other spectra pre-processing – example of pre-processing steps are shown in Figure 20. This lecture will demonstrate several kinds of preprocessing methods.

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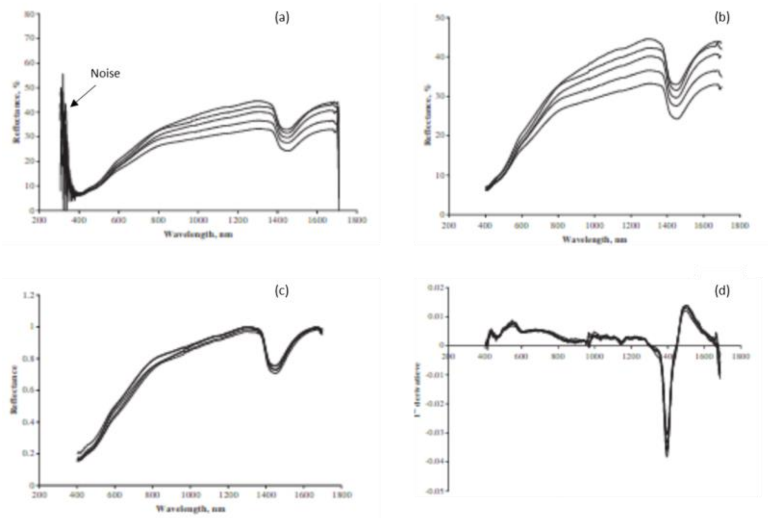

Figure 20: Preprocessing methods used to exclude noise from visible and near infrared (vis-NIR) spectra. (a) noisy spectra, (b) nose removed spectra (e.g., by cutting noisy parts and smoothing), (c) scaled spectra (e.g., by normalisation), (d) Reduce scatter effect and associated noise (e.g., by derivation and smoothing)

- Spectral modelling. Once the spectral data is processed with a proper set of preprocessing steps, the data will be divided into calibration and validation sets for spectral modelling (Figure 21). The calibration set will be used during regression model to predict the soil fertility parameters and the model will be validated with prediction set. The lecture will focus on using different multivariate and machine learning methods, which consist of several linear and non-linear modelling techniques used for soil characterization (Figure 22).

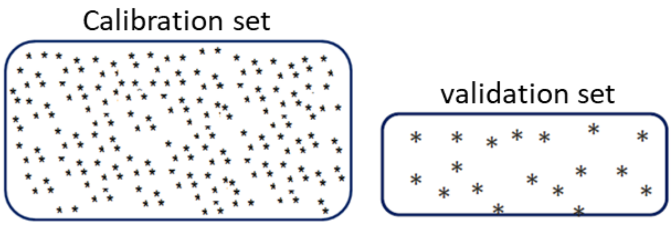

Figure 21: Partition of spectral data for data for data modelling. Calibration set (consisting of 70 % samples) and validation set (consisting of 30 % samples)

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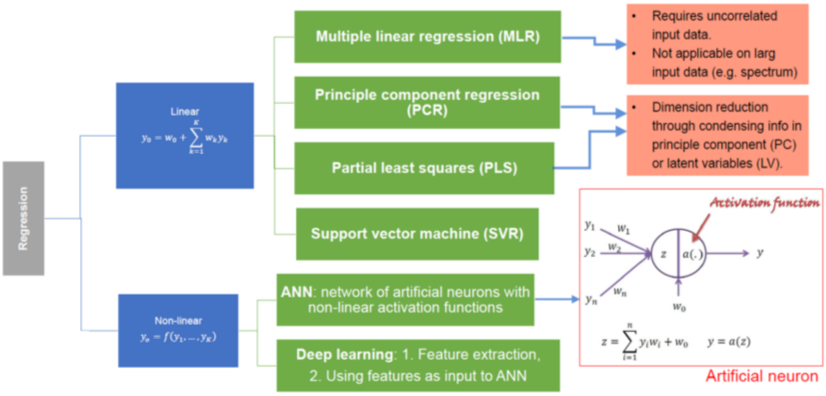

Figure 22: Classification of regression techniques used to produce linear model and non-linear spectra calibration models

- Soil data interpretation: The lecture will mostly focus on data interpretation methods which includes spectral pattern, chemical peaks, model accuracy and model error demonstrated by the model. To evaluate the model performance accuracy, parameters listed in Table 1 will be considered.

Table 1: Parameters to evaluate the visible and near infrared (vis-NIR) model prediction performance

Performance Criteria	Description	Formulae	Result
Standard error of prediction (SEP)	Measure of the spread of data error distribution Similar formula can be used to calculate SE of calibration, cross validation.	$SEP = \sqrt{1/_z \sum_{i=1}^{z} (y_i - \hat{y}_i - bias)^2}$	LOW
Bias	Arithmetic mean of predicted errors.	$Bias = 1/_z \sum_{i=1}^{z} (y_i - \hat{y}_i)$	LOW
Mean squared error (MSE)	Arithmetic mean of the squared errors Can be done calibration, validation and cross validation	$MSE = 1/_z \sum_{i=1}^{z} (y_i - \hat{y}_i)^2$	LOW
Root MSE (RMSE)	In case bias is negligible, RMSE = SEP	$RMSE = \sqrt{MSE}$	LOW
R-Square (R^2)	Strength of relationship	$R^2_{cal} = \frac{\sum_{i=1}^{N} (x_i - \bar{y}_i)^2}{\sum_{i=1}^{N} (x_i - \bar{y})^2}$	HIGH
Residual prediction deviation (RPD)	Standard deviation of observed values divide by SEP	$RPD = \frac{SD_{valset}}{SEP}$	HIGH

- **Mapping using Geostatistical software.** Further students will be trained to generate spatial distribution map of chemical components of soil using geostatistical software ArcMap. They will learn Geostatistical theory, which is concerned with the analysis and modelling of spatial interpolation and spatial stochastic simulation. In the ArcMap software they will use Kriging & Variogram modelling for spatial interpolation. Figure 23 shows an example of moisture content map developed after semivariogram modelling.

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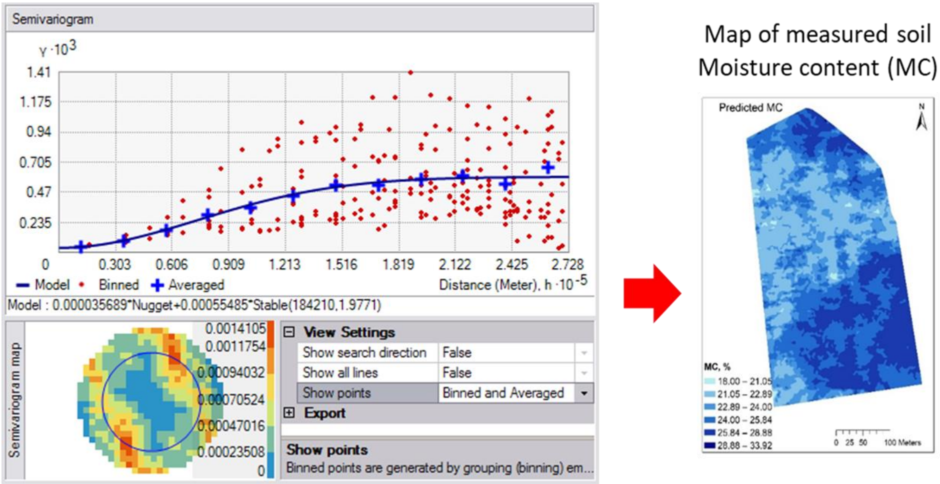

Figure 23: On-line soil moisture content (MC) map developed after semivariogram analysis using ArcMap Geostatistical software

2.7. Combining biofertiliser with precision agriculture (Module 2)

The plan for this Module 2 is shown in Figure 24.

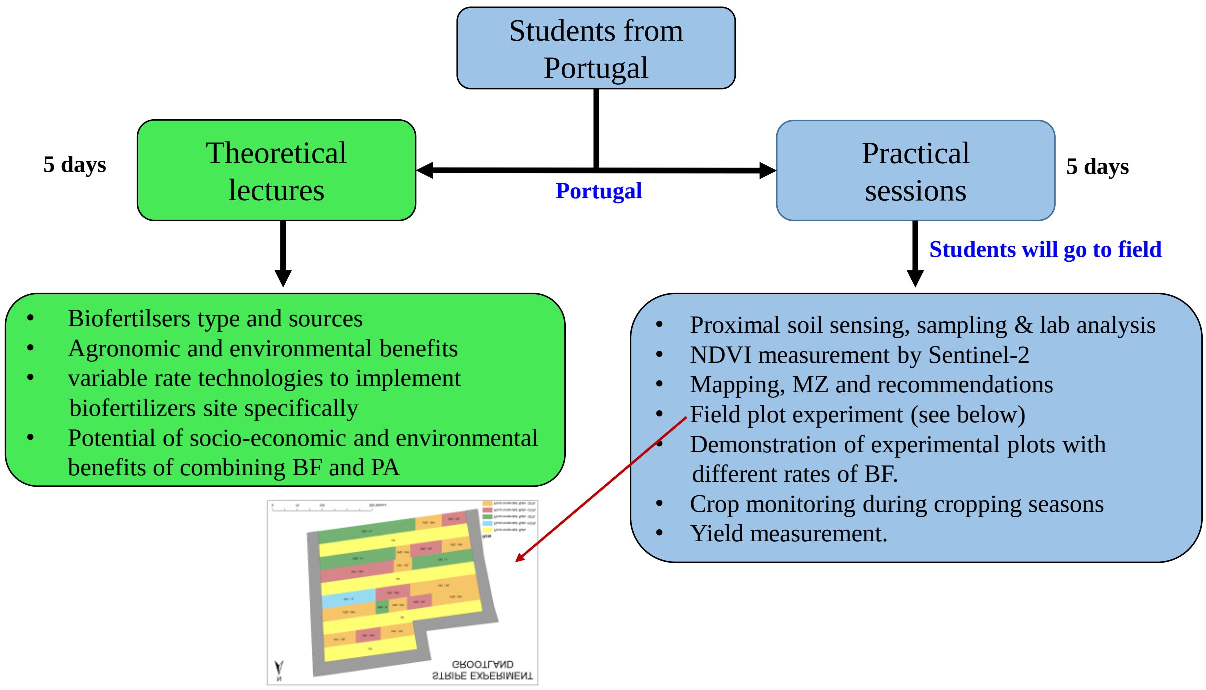

Figure 24: Planning for the Module 2 on combining biofertilizers and precision agriculture technologies

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2.7.1. Detail plan for the theoretical session

One or more aforementioned experts from UGENT, MIGAL, FC.ID & CIÊNCIAS will deliver lectures for this course. The detail description of theoretical session briefly outlined below:

- **Lecture on Biofertilizers (by Prof Cristina Cruz).** The lecture will focus on what is known about plant nutrition addressing its mineral, organic and symbiotic components with special attention to the plant core microbiota and microbiome. The concepts of resource bio-availability and symbiotic life style will be used to highlight the role of soil ecology in plant nutrition and nutrient use efficiency explaining why we need biofertilizers.

  - Biofertiliser type and sources: According to the actual EC definition a Biofertiliser is a product formed by microorganisms or substances produced by them and that when applied to the plant or to the soil promotes plant growth while improving soil health. Most of the biofertilizers available in the market originated from soil microbial isolates and are mainly bacteria, algae and fungi (including mycorrhiza and trichoderma). Most products are formed by microorganisms belong to more than one strain and work in consortium.

  - Agronomic and environmental benefits of Biofertiliser: Biofertilizers act by increasing nutrient bioavailability and/or by promoting the concerted action among the participants in the soil food web, which is a key factor to improve nutrient use efficiency. In soils and in support of intensive agriculture for long periods the use of biofertilizers may allow for the reduction of 30% of the recommended dose of mineral fertilization, while promoting the establishment and/or improvement of soil related ecosystem services such as reservoir of biodiversity (including pollinators), provision of good quality water or increased carbon sequestration.

- **Lecture on Variable rate technologies (Prof. Abdul M. Mouazen).** The lecture will demonstrate Variable rate technology (VRT). VRA is an aspect of precision agriculture that automates the application of farm inputs such as fertilizers, pesticides, manure and seeds according to the crop needs. The lecture will focus on below topics:

  - Variable rate technologies to implement farm input resources site specifically. These include machinery for manure application, fertilization, seeding, irrigation, and pesticide application (Figure 25).
  - Potential of socio-economic and environmental benefits precision application of farm input resources. To support the lecture aim, previous and current examples of site-specific applications of farm input resources will be presented.

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Figure 25: Application of variable rate technology in agriculture

2.7.2. Practical session - variable rate fertilization experiment

The experiment sessions will run on actual commercial or experimental fields in Portugal. The practical session consists of two sub-sessions: 1) demonstration of biofertiliser plots at CIENCIAS including crop and soil characterisation and 2) Establishment and running variable rate biofertilisation plots.

- **Demonstration of biofertiliser plots at CIENCIAS (Led by Prof. Cruz)**

The students can do some evaluation of difference agronomic indicators of the established biofertlieser plots at CIENCIAS using visual assessments, soil properties measurement and crop NDVI sensors.

- **Establishment and running biofertilization plots (Led by Dr. Lalit M. Kandpal)**

In order to evaluate the combined use of variable rate technologies under PA and biofertilizer use, we plan to establish variable rate biofertilizer experiment in 2-3 commercial fields in Portugal. The following are the different stages of running and evaluating the experimental output.

On-line soil sensing (Led by Dr. Lalit M. Kandpal):
The online multi-sensor platform of UGENT will be used to scan the soil in 2-3 selected commercial fields in Portugal. This necessitates the online sensor of UGent to be transported to Portugal to run the experiment. The detail protocol for the practical sessions for on-line soil sensing in given below.

- Assigning 2-3 fields each of 30-50 ha area to run the experimental work of site specific biofertilizer application
- A tractor of 60hp, and a driver that needs to be trained before the measurement.
- The tractor will be driven at 3km/h, driving at parallel lines 15m apart. The subsoiler will be put at 15 cm depth

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- A pneumatic fertilizer spreader of granular fertilizer, or a sprayer for liquid fertilizer will be needed. They have to be equipped with PA technologies including GPS, control system for variable rate application.
- A combine harvester equipped with a yield sensor.
- The online soil measurement needs to be done after crop harvest but before tillage
- About 150-200 soil samples will be collected during the online measurement to be analyzed for organic carbon, P, K, Mg, Ca, CEC, moisture, pH and Na.
- The experimental fields are irrigated, with one light soil, medium and one heavy soil textures.
- After on-line measurement and laboratory analyses are completed, UGENT will develop calibration models to transfer the spectral data into quantitative values of the above list of soil properties.
- Models will be used to predict the above list of soil properties, using on-line collected soil spectra. The predicted properties will be used to develop corresponding maps.

NDVI measurement (Led by Dr. Lalit M. Kandpal)

- In addition to the soil measurement described above, we will need data on NDVI obtained with Satellite imagery (AgriSat). The NDVI data will be needed in 2020, 2021 and 2022 (using Sentinel 2 data) about 1 week before each time of fertilization (2-3 times).
- The NDVI data will be fused with on-line soil data and yield (measured by means of a yield sensor on a combine harvester) of the previous cropping season (e.g., 2019, 2020 and 2021 yield maps), to develop management zone map (MZM) for VR N fertilization.
- K and P fertilization recommendation will be directly derived from the predicted value of P and K obtained in Point 2.

Implementation of variable rate fertilization of N, P and K (Led by Dr. Lalit M. Kandpal)

- Each field will be divided into plots each 24 m wide. Half of the plots will be used for variable rate bio-fertilization and the other half for uniform rate bio-fertilization. The uniform rate bio-fertilization will be according to the Portuguese calculated rate based on traditional methods of fertilization recommendation.
- For the variable rate plots, the treatment will be divided into different levels depending on the number of classed obtained in the MZM developed (see Figure 26). Class (zones) with average fertility will be assigned the same rates (recommendation) as for the homogeneous plots. However, the poorest fertility zone will need to receive 75% more rate (if adopting the Robin Hood approach of feeding the poor) or less (if adopting the Kings approach of feeding the rich, to

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maximize the production of the most fertile zones). These two treatments will be compared against the homogeneous (uniform) rate application, to be named as the control treatment. At the end of the cropping season, the yield data will be used together with the input fertilizer used to evaluate the economic benefits by running a cost-benefit analysis by UGent team. Changes in soil biology and fertility will also be evaluated by partner FC.ID.

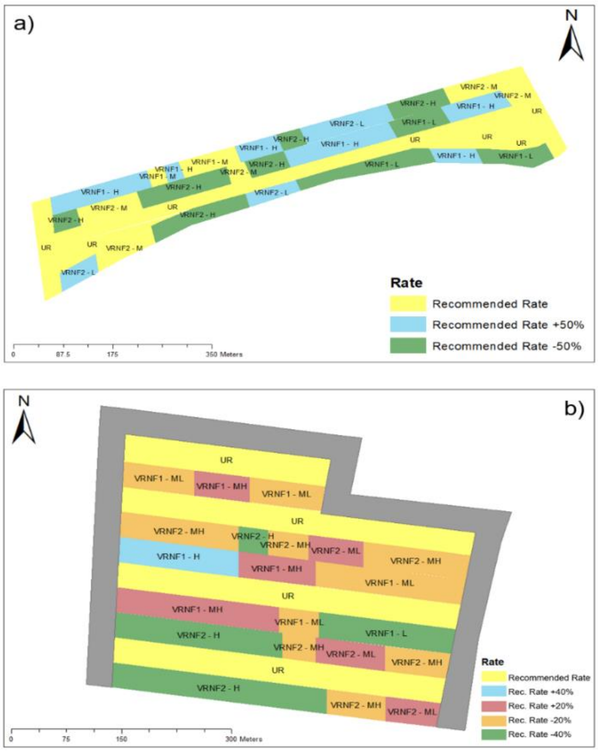

Figure 26: Example of the strip experiments, developed based on management zone maps (MZ), delineated with online measured soil fertility attributes and satellite derived normalized difference vegetation index (NDVI)

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3. Calendar and Schedule

Table 2: Training program agenda outline (Module I)

Year: Feb-April 2022**; Location:** Portugal**; Date/Time:**				
Schedule	**Activities**	**Instructor/s**	**Course description**	**Partners**
Day 1 (7 hr)	Proximal soil sensing course	Prof Litaor	Theoretical lectures • Geophysical techniques	MIGAL
Day 2 (7 hr)	Proximal soil sensing course	Prof Litaor	Practical session • How to use the instrument • Calibration • Manual operation versus automated mode	MIGAL
Day 3 (8 h)	Proximal soil sensing course	Prof. Litaor	Practical session • Data analysis using R codes. • Spatial analysis • Management Zones (MZ) delineation • Demonstration of EMOA (evolutionary multi-objective analysis	MIGAL
Day 4 (7 hr)	Proximal soil sensing course	Prof. Litaor	Practical session • Soil sampling • Soil analysis	MIGAL
Day 5 (5 hr)	Proximal soil sensing course	Prof. Litaor	Practical session • Demonstration of statistical analysis for MZ verification and use	MIGAL
Day 6 (5 hr.)	Proximal soil sensing course	Prof Mouazen	Theoretical lectures • Optical techniques	UGENT

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Day 7 (5 hr.)	Proximal soil sensing course	Prof Mouazen	Theoretical lectures • Electrochemical technique • Gamma ray technique • Multi-sensor data-fusion	UGENT
Day 8 (3.5 hr.)	Proximal soil sensing course	Dr. Lalit	Practical sessions on: • Demo on UGent sensing platforms • Demo of UGent laboratory spectroscopy methods	UGENT
Day 8 (3.5 hr.)	Proximal soil sensing course	Dr. Lalit	Theoretical lectures • Data analysis techniques • Mapping techniques	UGENT
Day 9 (8 hr.)	Proximal soil sensing course	Dr. Lalit	Practical assignments • Field trips & field measurement • Soil sample preparation • Spectra collection	UGENT
Day 10 (8 hr.)	Proximal soil sensing course	Dr. Lalit	Practical assignments • Modelling of collected spectra • Mapping using Geostatistical software	UGENT

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Table 3: Training program agenda outline (Module 2)

Year: Feb-April; **Location:** Portugal; **Date/Time:**				
Schedule	**Activities**	**Instructor**	**Course description**	**Partners**
Day 1-2 (5 hr/day)	Proximal soil sensing course & Biofertiliser application	Prof. Cruz	Theoretical lectures • Biofertilisers type and sources • Agronomic and environmental benefits of biofertilisers	FCID
Day 3-4 (5 hr/day)	Proximal soil sensing course & Biofertiliser application	Prof. Mouazen	Theoretical lectures • Variable rate technologies • Potential of socio-economic and environmental benefits of c variable rate technologies	UGENT
Day 5-6 (7 hr/day)	Proximal soil sensing course & Biofertiliser application	Prof. Cruz	Practical session: • Demonstration of biofertiliser plots at farms at CIENCIAS.	FCID and CIENCIAS

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Day 7-10 (6 hr./day)	Proximal soil sensing course & Biofertiliser application	Dr. Lalit	Field experiment on VR fertilization • Soil sensing • Sampling and lab analysis • Modelling and Mapping, • Management zone delineation (MZ) • Recommendations for variable rate fertilisation • Field plot experiment to compare between uniform rate against variable rate fertilizer application. • Crop monitoring during cropping seasons, • Yield measurement at the end of the cropping season	UGENT / MIGAL / FCID and CIENCIAS

4. Reference

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