

Executive summary

The multidisciplinary DIGISOIL consortium intends to **integrate and improve *in situ* and proximal measurement technologies for the assessment of soil properties and soil degradation indicators, going from the sensing technologies to their integration and their application in (digital) soil mapping (DSM)**. In addition, our SMEs experiences contribute to take **into account the feasibility of developments based on economical constraints, reliability of the results and needs of the DSM community**.

In order to assess and prevent soil degradation and to benefit from the different ecological, economical and historical functions of the soil in a sustainable way, there is an obvious need for high resolution and accurate maps of soil properties. The core objective of the project was to explore and exploit new capabilities of advanced geophysical technologies for answering this societal demand (Figure 1). To this aim, DIGISOIL addressed four issues covering technological, soil science and economic aspects: (i) the validation of geophysical (in situ, proximal and airborne) technologies and integrated pedo-geophysical inversion techniques (mechanistic data fusion) (ii) the relation between the geophysical parameters and the soil properties, (iii) the integration of the derived soil properties for mapping soil functions and soil threats, (iv) the evaluation, standardisation and sub-industrialization of the proposed methodologies, including technical and economic studies.

With respect to these issues, the milestones of the DIGISOIL project were:

1. To develop, test and validate the most relevant geophysical technologies for mapping soil properties: **geoelectric, seismic, GPR/EMI, magnetic and airborne hyperspectral**;
2. To establish correlations between the measured geophysical measurements and the soil properties involved in soil functions / threats (**erosion, compaction, organic matter decline, salinisation and shallow landslides**) by using innovative data processing (inversion) and correlation protocols;
3. To evaluate the societal impact of the developed techniques by investigating their relevance relative to the end-user needs, the technical feasibility and the cost effectiveness;
4. To produce an exploitation plan, including the standardization of the processes and the technical specifications of the developed methodologies describing the system components in terms of equipment (sensors, acquisition system, mobile vector), techniques (signal processing, inversion or fusion processes, specialization) and operational protocols.

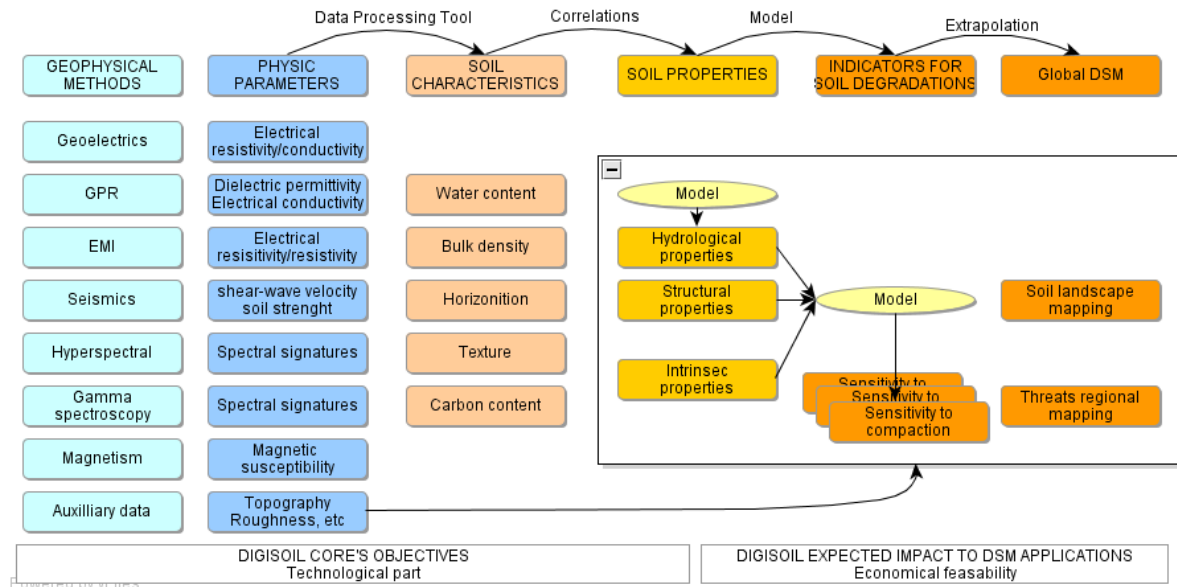


Figure 1: Digisoil's concept

Description of the project context and objectives

The DIGISOIL project can be seen as a setting of operational techniques useful for implementing existing and emerging EU environmental legislation and policy, like the Soil Thematic Strategy, which aims to protect soil functions and prevent soil degradation.

Since 2002, the European Commission considers the soil as a non-renewable resource threatened by natural hazards and human activities (COM179/2002). Erosion, organic matter decline, contamination, sealing, compaction, salinisation, floods and landslides have been identified as the main soil threats. The implementation of the Soil Thematic Strategy (COM232/2006) implies that Member States individuate risk areas for erosion, organic matter decline, compaction, salinisation and landslides. For soil contamination, an inventory of contaminated sites should be undertaken. Concerning risk area delineation, soil and soil-related parameters (refer to as auxiliary data by the DSM community) should be considered in the mapping model.

In the last decades, geophysical prospecting applied to the subsurface characterization has been of an increasing interest, particularly in Soil Science. Major advances in this technological domain can be attributed to the development of integrated measure systems, increasing computing power, equipment portability and hardware/software diffusion. In this context, two kinds of technological platforms can be involved: ground-based and proximal technologies, respectively working from the surface and from an airborne vector. Ground-based geophysical instruments are now equipped with digital signal processing and recording capabilities previously restricted to large corporate computing centres. This improved computational capacity has provided investigators with near real-time results that, in turn, drive improvements in instrument sensors and processing algorithms. Identically, recent airborne geophysics sparked off a strong interest due to the possibilities of flights with civil airplanes equipped with optical, thermal or hyperspectral sensors.

Considering the new equipment and signal processing developments offered by recent scientific exploitations, the problem of carrying out soil data collections at the catchment scale using geophysical sensors can be foreseen in the near future, particularly for identified methods such as GPR, EMI, seismics, magnetics and airborne hyperspectral. Gravity and thermic methods were not incorporated in DIGISOIL approach because of their low contribution to the characterization of soil properties related to above-cited degradation processes. For gammametry, several research actions have already been carried out to study the potential for soil properties mapping. This technology has given satisfactory results

and permits to map types of clay minerals in the topsoil through the analysis of U, K, Th anomalies in the gamma spectrum. We did not consider this method since it appears to be already used in the soil science community.

To fulfil our ambitions, some important issues were tackled prior to the definition of a project work plan. These issues framed the DIGISOIL activities in order to preserve the technical and economical relevance of the project's results. The first step was to establish a short list of the soil properties described in the previous sections according to their potential identification with geophysical data:

- a. Properties which can be identified requiring limited further research: this is the case of the geoelectrical resistivity, EMI and radar signals for characterizing soil properties like salt concentration, packing density, moisture or texture. These properties were included in the DIGISOIL perimeter as they refer to well-known techniques;
- b. Properties likely to be identified through significant research investment: this is the case of the estimation of the carbon content by using magnetic or hyperspectral/spectroscopy data, or the estimation of compaction by using seismic methods. These approaches were tested in the DIGISOIL project, hyperspectral techniques being considered as to be explored;
- c. Properties difficult to identify: this is the case of diffuse concentrations of chemical elements (trace elements: nitrate, pesticides). This parameter was not integrated in the project.

According to the above classification, the development of an integrated system of (*in situ* or airborne) imaging technologies for collecting and mapping soil properties were based on both well-known geophysical technologies that were coupled and integrated in an original way as well as on innovative measurements which are needed to go beyond current state of the art technologies (soil texture, organic matter content, soil water content):

Well-known geophysical technologies	Innovative measurement technologies
Electromagnetic method (EMI)	Seismic (surface waves)
Ground-penetrating radar (GPR)	Magnetic
Electrical methods (Geoelectric)	Field and airborne hyperspectral techniques

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3. To evaluate the societal impact of the developed techniques by investigating their relevance relative to the end-user needs, the technical feasibility and the cost effectiveness;
4. To produce an exploitation plan including the standardization of the processes and the technical specifications of the developed methodologies describing the system components in terms of equipment (sensors, acquisition system, mobile vector), techniques (signal processing, inversion or fusion processes, specialization) and operational protocols.

Description of the main S&T results/foregrounds

WP1 – Development of new sensing technologies

Context

The general objective of WP1 was to develop and implement jointly advanced sensing techniques for non-invasive characterization and monitoring of the soil geophysical properties as surrogates for the soil physical and hydrological properties which are relevant to the Soil Thematic Strategy. For the soil electrical properties, the selected sensors within the DIGISOIL strategy are: geoelectric (0.01-10 Hz), electromagnetic induction (EMI) and magnetic (1-100 kHz), ground penetrating radar (GPR, 200-2000 MHz), and near-infrared/visible spectroscopy (120-857 THz), thereby providing complementary information over a very large frequency band. For the soil mechanical properties, micro-seismic is used. WP1 entails three tasks, namely, (1) improving and/or adapting the geophysical sensors, (2) optimising data processing algorithms for full use of sensor information and maximal accuracy, and (3) synthesising sensor and processing approaches to build an integrated measurement platform for real-time and high-resolution mapping of the soil properties.

WP1 encompassed three major tasks:

- **Task 1.1. Improved sensor specifications**

Sensor prototypes previously developed by the partners and state-of-the-art sensors were implemented and adapted to permit real-time characterization of the soil with a high spatial resolution. This included optimization of instrument design (e.g., antenna design) and adaptation of instrument settings for soil imaging (e.g., operating frequency).

- **Task 1.2. Signal processing optimization**

In order to reach the physical frontiers of information retrieval from the different sensors, signal processing should be based on advanced mechanistic inverse modelling. Efforts focused on improved signal understanding, forward modelling, and inversion using global optimization and regularization techniques to estimate the soil geophysical parameters of interest. This task was supported by the realization of laboratory and field experiments in well controlled conditions (see also WP2).

- **Task 1.3. Description of measuring and processing protocols**

For each sensor and given feedbacks from WP2 and WP3, measuring and processing protocols were developed and standardised, including instruments settings, sensor calibration, measurements, and processing algorithms.

Significant results

- **Geoelectric**

Geoelectric measurements are performed using the MUCEP system developed by CNRS Garchy. The system is composed by a SYSCAL acquisition station and a series of electrodes mounted on metallic wheels; a Doppler radar triggers measurements every 10 cm along parallel profiles. The positioning of the data points is done by differential GPS. The sensor part shows 3 quadrupoles configured in a “V shape” mode for optimizing signal to noise ratio. Electrodes spacing are 0.5, 1 and 2 m for each electrode quadrupoles, respectively (Figure 2). While the system is moving, measurements are realised in a continuous mode by the mean of a 150 milli-second time pulse. In the same time, signals are recorded according to the 3 acquisition channels by the SYSCAL station. Several inversion algorithms may be used to retrieve soil electrical resistivity from geoelectric data, notably the QWIN1D software (Cousin et al., 2009) or RES2DINV (Loke and Barker, 1996). Then, for comparison purposes amongst measurements carried out at different dates, electrical resistivity values are corrected for temperature (Keller and Frischknecht, 1966). Soil water content and soil texture are retrieved from electrical resistivity using correlations established from soil samples between these quantities (Besson, 2007). As an example, maps soil water content estimates from geoelectric measurements are presented in Figure 3 for two different seasons.

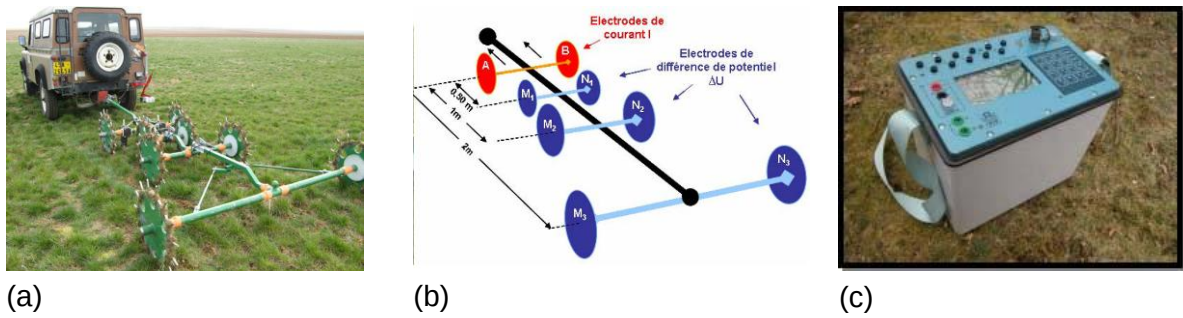


Figure 2 - (a) Photo and (b) sketch of the MUCEP system, and (c) de SYSCAL acquisition station.

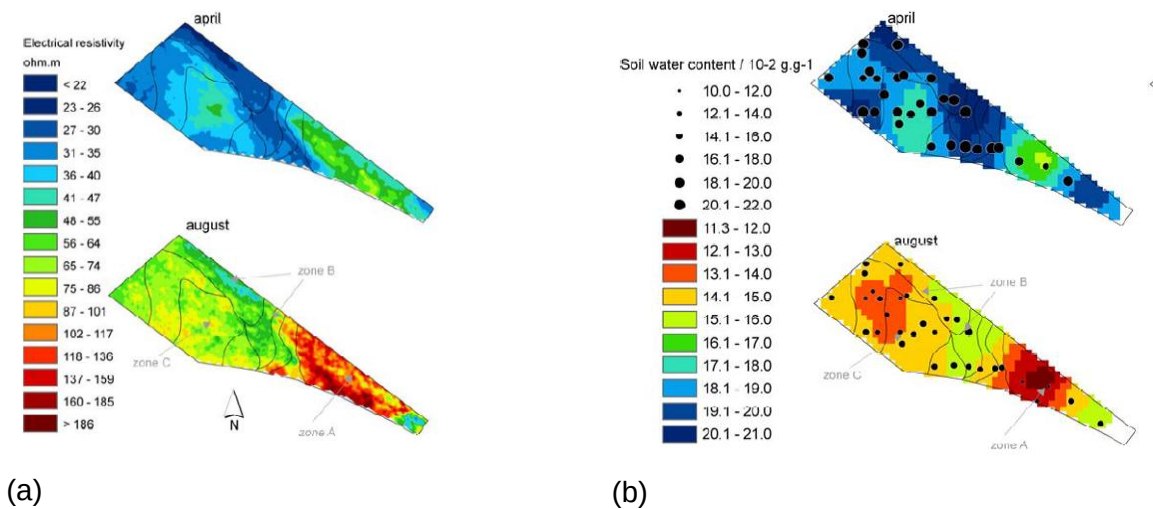


Figure 3 - Maps of (a) electrical resistivity and (b) water content estimates for a parcel at two different season (Besson, 2007).

• Seismic

Three seismic sensors were investigated in DIGISOIL: (1) vertical component geophones of 10 Hz central frequency from Geospace, (2) vertical component geophones of 100 Hz central frequency from Mark Products, and (3) tractable gambles of 10 Hz central frequency from Mark Products (Figure 4). Three distances between receivers were considered: 10, 20 and 50 cm. Shot points were systematically set at 50 cm from the first receiver. Optimal spacing that allows a precise velocity picking on the dispersion diagram is 50 cm because the maximum energy can be clearly observed on the whole bandwidth and propagation modes can be distinguished with accuracy. The 10 Hz geophones or gambles offer a large coverage of the whole frequency band and stay in good agreement with the required objectives. The fundamental and first modes are well identified in the dispersion diagram. As this tool was made available only recently, there are not yet scientific studies which demonstrated its performances. Processing of seismic data consists in performing dispersion analysis of surface waves in order to obtain dispersion curves, i.e., the plot of phase velocity versus wavelength (McMechan and Yedlin, 1981). Shear waves velocity and layer thicknesses are retrieved by inversion minimizing the residues of the phase velocity computed as differences between real and synthetic dispersion curves (spectral analysis and inversion). From the shear wave velocity, bulk density with depth can be reconstructed using either empirical or more conceptual petrophysical relationships. An example of DIGISOIL seismic data product is shown in Figure 5.



Figure 4 - (a) Vertical component geophones of 10 Hz central frequency (Geospace), (b) vertical component geophones of 100 Hz central frequency (Mark Products), (c) tractable gambles of 10 Hz central frequency (Mark Products).

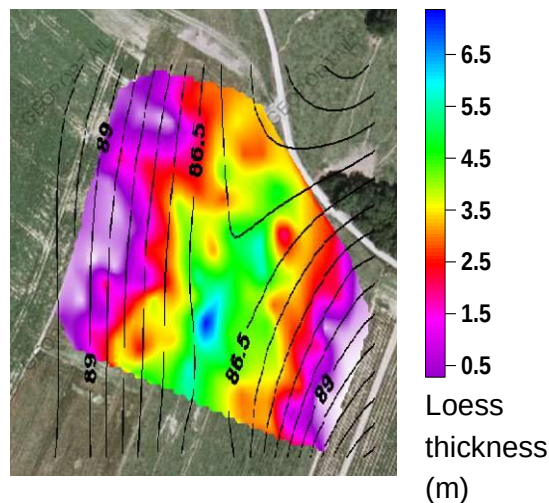


Figure 5 - Map of loess thickness (m) estimated from the seismic data at the BRGM test site.

- **Ground penetrating radar**

Two GPR sensors were investigated in DIGISOIL (Figure 6) : (1) a frequency-domain, zero-offset, off-ground GPR prototype designed with vector network analyzer (VNA) technology and an off-ground directive horn antenna, and (2) a time-domain, bistatic ground-coupled commercial system. A major advantage of the VNA over traditional radars is the accurate calibration of the system, which is an international standard, thereby ensuring proper repeatability of the measurements. The on-ground system permits deeper characterization. The soil hydrogeophysical properties are estimated through full-waveform inverse modelling. For the off-ground radar configuration, the previously model of (Lambot et al., 2004) is used. For the on-ground system, we extended that model to account for near-field effects, which provided groundbreaking results in the area of GPR (Lambot et al., submitted to GPR 2010). Figure 6(c) shows a high-resolution map of the soil surface water content at the UCL test site (~5 ha) in central Belgium.

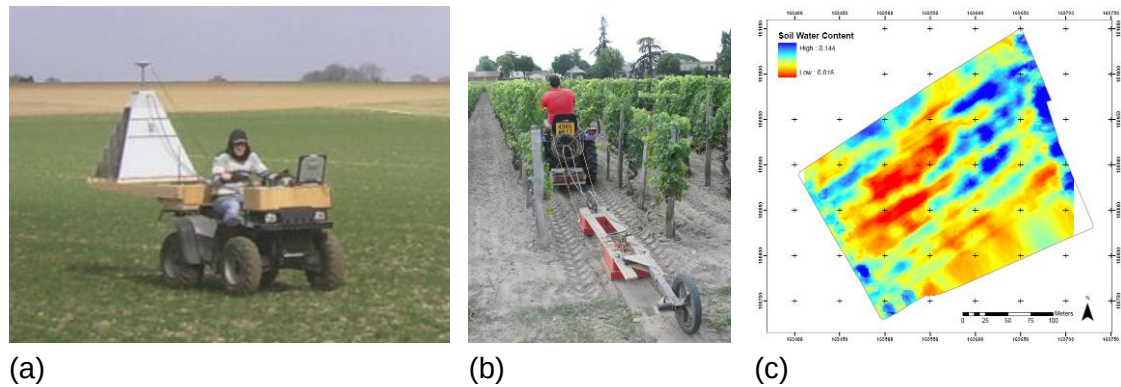


Figure 6 - (a) Off-ground GPR prototype, (b) on-ground commercial system, (c) GPR derived soil moisture map.

- **Electromagnetic induction**

Three electromagnetic induction (EMI) sensors were investigated in DIGISOIL: (1) the EM38 from Geonics, that is commonly used for mapping the soil electrical conductivity in agricultural fields; (2) the new EMP-400 Profiler from GSSI; and (3) a prototype sensor that is being developed by FZJ and UCL within the DIGISOIL project (Figure 7). An advantage of the EMP-400 over the EM38 is its ability to simultaneously measure at three different operating frequencies in the range 1-16 kHz, thereby increasing the information retrievable from the soil. As this tool was made available only recently, there are not yet scientific studies which demonstrated its performances compared to the traditional EM38. Compared to the two commercial systems, the searched advantages with the prototype development are (1) a standardised calibration procedure to ensure proper repeatability of the measurements, and (2) a fully mechanistic signal processing based on three-dimensional (3-D) electromagnetic forward and inverse modelling (Moghadas et al., 2010). In the near future, full-waveform inverse modelling will also be used to process EM38 and Profiler data applying to EMI the model recently developed for on-ground GPR (Lambot et al., submitted to GPR 2010). After correction for temperature (Sheets and Hendrickx, 1995), soil physico-chemical properties (water content, clay content, salinity) may be estimated from soil electrical conductivity measurements using petrophysical relationships (Archie, 1942; Rhoades et al., 1976; Shah and Singh, 2005). As an illustration, Figure 8(a) presents a map of soil electrical conductivity measured with EM38 at the FZJ test site, and corresponding water content estimates are shown in Figure 8(b).

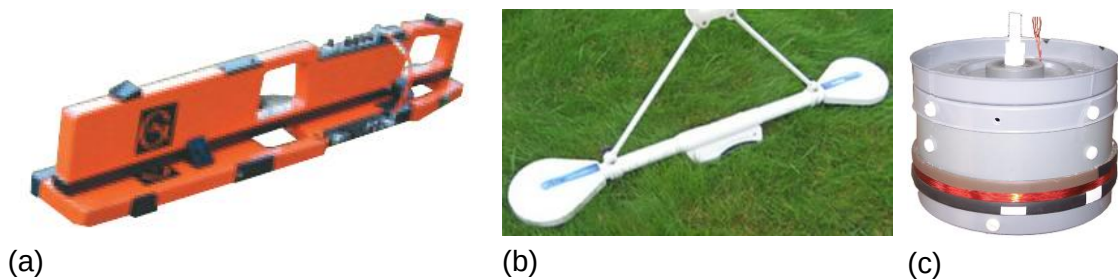


Figure 7 - (a) EM38, (b) EMP-400 Profiler, (c) EMI prototype.

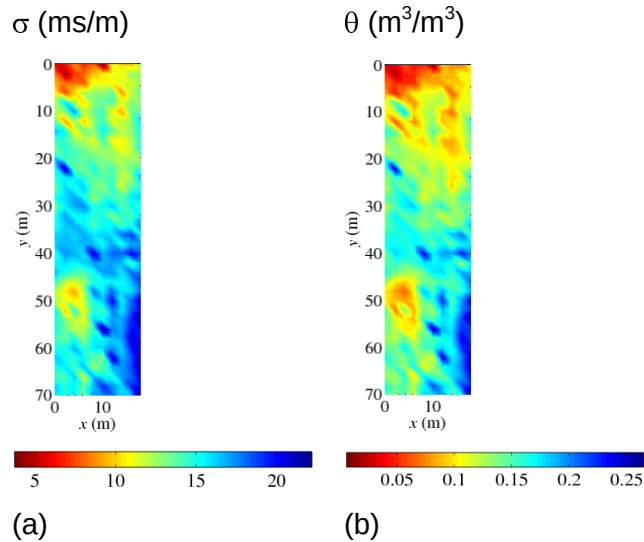


Figure 8 - (a) EM38 soil electrical conductivity measurements and (b) corresponding water content estimates at the FZJ test site.

- **Magnetics**

We compared here the commercial MS2D (Bartington Ltd) and TS6 (Protovale) and prototypes (Sisyphé) CS60 and VC100 magnetic sensors for measuring the soil magnetic susceptibility and magnetic viscosity up to a depth of about 40 cm (Figure 9). The sensors provide directly the soil magnetic properties after calibration and under the low induction number assumption. Corrections factors are applied depending on the geometry of the loop and dimensions of the bucket. The main operational conditions and limits of the methods are the same as for EMI. In fact, the measurements of the magnetic properties require stable geometries. The correction of the drift caused by the mechanical strain mainly linked to temperature variations has to be done before any transform of the in-phase value into magnetic susceptibility.



Figure 9 - (a) MS2D, (b) TS6, (c) CS60 prototype, and (d) VC100 prototype magnetic sensors.

- **Hyperspectral**

We used the airborne hyperspectral Galileo Avionica SIM-GA HYPER 512 + 256-spectral-band push-broom sensor with VNIR and SWIR imaging capabilities, covering the 400-2450 nm spectral region and operated on board of the UNIFI ultra-light aircraft FOLDER at about 1000 m of altitude. The hyperspectral images are processed according to the Galileo Avionica processing chain generating and distributing, through a specific calibration procedure, the defined radiance and reflectance data set over the study areas (see Deliverable D1.3). Corrections are applied to the data, including exposure time, dark, defective pixel, far field and gain coefficient corrections. There are two approaches generally adopted to retrieve a given property from remotely acquired spectral data: (1) the physical approach which involves the inversion of a Radiative Transfer Model (RTM) describing

accurately the reflectance of an object as a function of its surface geometry and chemical/physical characteristics, and empirical or statistical approaches with multivariate calibration procedures. These last, as adopted in DIGISOIL, are usually more appropriate when dealing with complex environments such as soils. Figure 10 shows an example of hyperspectral image product acquired at the Luxembourg test site.

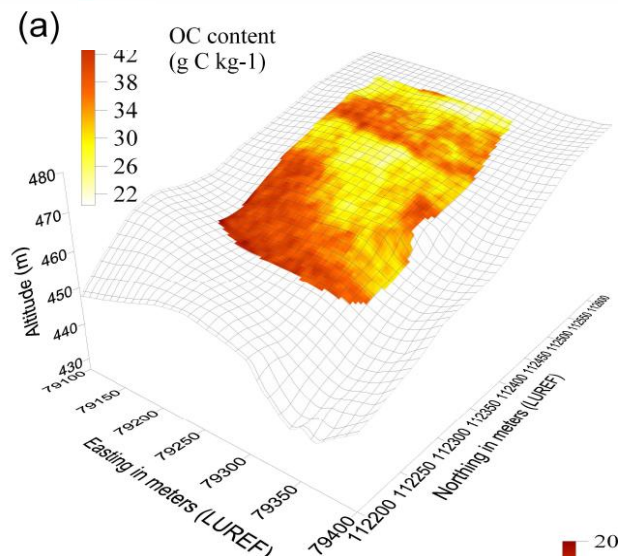


Figure 10 - SOC content map derived from hyperspectral data at the Luxembourg test site.

WP2 – Geophysical data integration and soil properties collection

Context

The estimation of soil characteristics and their consecutive mapping from geophysical measurements are not straightforward. They require a set of data processing tools, as data inversion, calibration, correction and conversions, which may result each one in a large degree of uncertainty on estimations, overwhelming in some extent the real in-field soil variability. In consideration to this, Workpackage 2 (WP2) on “Geophysical data integration and soil properties” aimed at interpreting the geophysical sensors signals firstly into geophysical parameters and secondly into soil properties. The specific objectives consisted then (1) in testing separately, in laboratory and calibration sites, the efficiency of advanced sensing techniques (developed in WP1) to predict changes in soil characteristics and (2) in developing an innovative approach of data integration in view of estimating and mapping soil characteristics with accuracy.

WP2 encompassed then three tasks:

- **Task 2.1: From geophysical signals to physical parameters.**

It consisted in reviewing all possible processing techniques described in literature, from geophysical measurements to soil characteristics mapping. This overview aimed at giving first recommendations as for the implementation of the general processing workflow.

- **Task 2.2: Laboratory or field calibration in controlled conditions.**

It consisted in refining processing tools, i.e. calibration and correction of data obtained by each sensing technique. Techniques were tested in field under controlled conditions and in laboratory.

- **Task 2.3: Inference of soil properties.**

From recommendations and results of both tasks 2.1 and 2.2, the task 2.3 aimed at detailing a general processing workflow that was fully implemented in Workpackage 3.

Significant results

Processing techniques described in literature were reviewed in deliverable D2.1. It results in developing a first general processing workflow and offers main recommendations in term of

data correction and calibration implemented for each advanced sensing technique. Experiments in laboratory and in calibration sites were realized also within the reporting period. As described in WP1, they implied geoelectric sensors, GPR, EMI, magnetic methods and hyperspectral measurements. Experiments and techniques used were considered separately. From results, the efficiency and limits of tested sensing methods, from measurements to soil characteristics estimations, were discussed in deliverable D2.3 relative to Task 2.2. Digisoil processing tool was finally developed and detailed in deliverable D2.2 relative to Task 2.3. It consists in an innovative data integration based on data fusion strategy.

Main results of experiments realized on calibration sites (see D2.3) are summarized in **Erreur ! Source du renvoi introuvable..**

Geophysical tool	Variable of interest	Punctual experiment or temporal monitoring	Nature of the experiment	Site of the studied soil	Soil type	Ancillary data	Main result
Electrical conductivity (Measurements on cylinders of disturbed soil samples)	Bulk density and water content	Punctual experiment	Laboratory experiment	INRA experimental site of Mons-en-Chaussée (France)	Luvisol	Temperature	Empirical rule between electrical conductivity, water content and bulk density
Electrical conductivity (ECT)	Bulk density	Temporal monitoring (from 15th April and not finished yet)	Field experiment	Beauce site (Villebon, France)	Luvisol	Water content (TDR), bulk density (soil cylinder), temperature (thermometric probes)	Identification of compacted clods and analysis of structural changes in time
Electrical resistivity (ERT)	Geologic structure (landslides)	Punctual experiment	Field experiment	Telega site (Romania)	Saline soil		Electrical methodology adapted to identify landslides
GPR and EMI	Water content	Temporal monitoring (25 days)	Field experiment	Selhausen site (Germany)	Haplic Luvisol	Water content (TDR)	Map of estimated water content from GPR and EMI signal
GPR	Water content (with the presence of shallow thin layer)	Punctual experiment	Laboratory experiment and field experiment	Center of Belgium (for the field experiment)	Sand (for laboratory experiment) and silt loam (for the field experiment)	Water content (volumetric sampling)	Map of surface soil water content retrieved by two-layered model (first and second layers) from GPR signal
Magnetic viscosity and susceptibility	Carbon content and clay content	Punctual experiment	Laboratory experiment	79 samples chosen in the soil french database	Wide range of soil for different class of clay content and carbon content	Information from the french data base: mineralogy, texture, chemical composition	Trend between magnetic properties and carbon and clay content
Airborne hyperspectral and field spectrometry	Clay content	Punctual experiment	Field experiment	Mugello (Italia)	calcareous Regosols, luvic luvisols, humic Umbrisols, anthracic Cambisols	minerals, mineralogic composition, iron oxides and $CaCO_3$	Possibility to map total clay content in soils from remotely sensed images
Hyperspectral	Carbon content	Punctual experiment	Laboratory experiment	Grand Duchy (Luxembourg)	Dystric Regosol, Dystric Cambisols	Soil roughness	Correlation between BRD and sensor viewed shadow. Analysis of BRD related effect
Seismic: Spectral Analysis of Surfaces Waves (multichannel application)	Soil thickness	Punctual experiment	Field experiment	Bourville (Normandy, France)	Loess material over clay	Dynamic resistance (PANDA Penetrometer)	Map of soil thickness
Seismic/geoelectric: Spectral Analysis of Surfaces Waves combined with ERT	Soil depth	Punctual experiment	Field experiment	Roujan	Calcaric Cambisol and Calcisol	Boreholes	Data fusion method developed

Table 1 : Synthesis on general results of experiments realized on calibration sites

From review and results detailed respectively in deliverables D2.1 and D2.3, the general processing workflow was developed (Figure 11). It gathers there main processing steps, i.e. (1) the joint inversion of raw geophysical dataset, (2) the conversion of the geophysical parameters into soil variables and (3) the fusion of maps obtained for each soil variable at the scale of interest. Processing steps, hence implemented in the inference approach, are all based on data fusion strategy in view of reducing uncertainty on estimates and then mapping soil characteristic with accuracy.

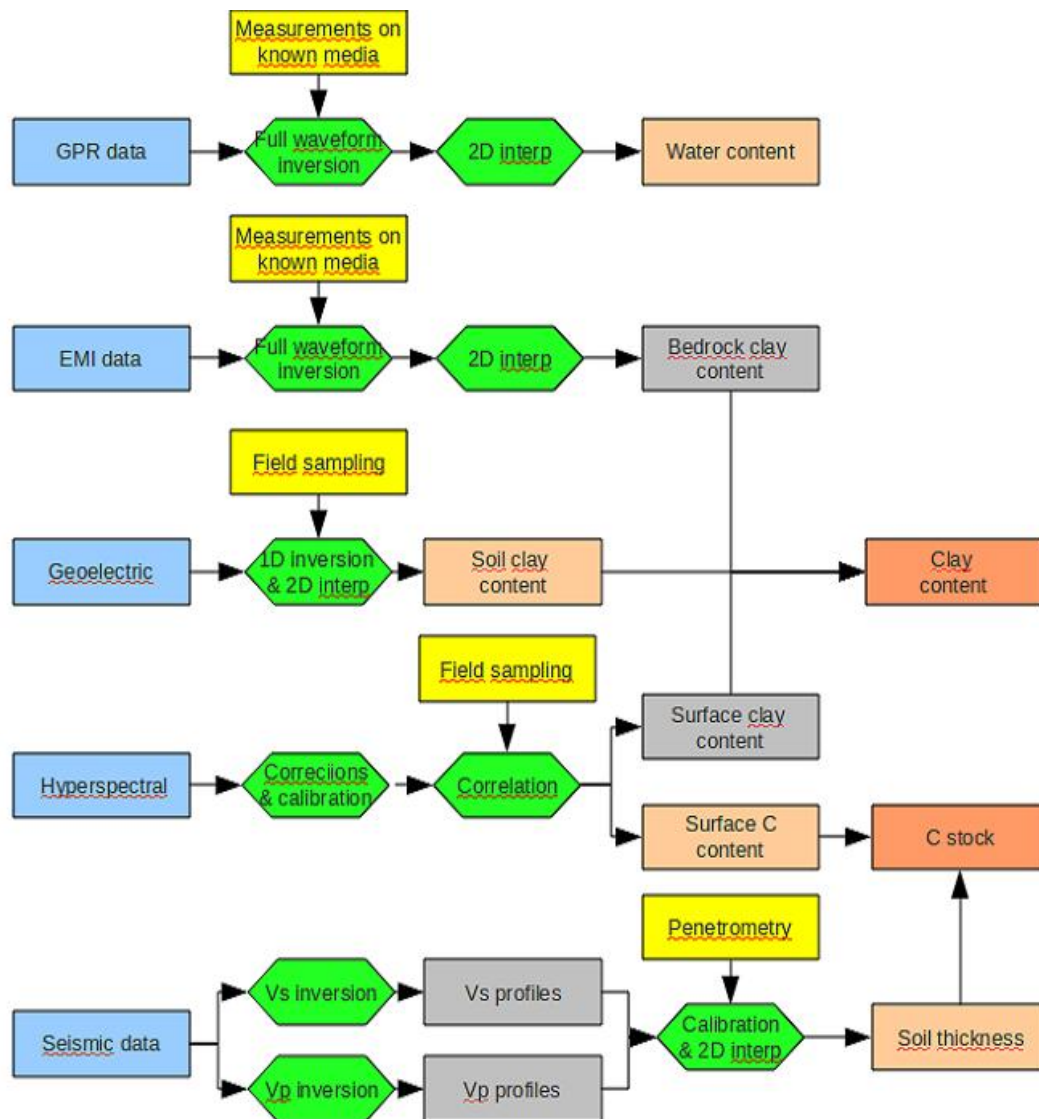


Figure 11 - Scheme of the general processing workflow

WP3 – Implementation, field testing and validation on selected test sites

Context

This work package aimed to i) map dynamic soil properties identified as common criteria for delineating the risk of soil threats (SOC decline, compaction, erosion and shallow landslides), ii) map the state of soil degradation, iii) calibrate and validate geo-physical techniques. A number of sites with different soils, agricultural management and climate have been selected on the basis of data availability and their suitability to demonstrate their vulnerability to different soil threats. The inference models developed in WP2 (Figure 11) was applied for mapping at the field scale: calibration and validation using traditional sampling and analysis of soil properties were also performed. The focus was on six main soil properties: C content, clay content, stone content, soil thickness, bulk density and water content.

Task 3.2 Geophysical measurements

The inference functions and fusion techniques developed in WP2 were applied to the field conditions of the different test sites. When possible, geo-referenced data sets were used for calibration of the geophysical techniques. Additional analyses were required to fill the gaps in the data sets and cover the selected dynamic soil properties.

Task 3.3 Validation

Validation of the geo-physical techniques was based on two sets of criteria: i) accuracy of the measurements as estimated by RMSE or RPM, and ii) their capacity to represent spatial patterns and spatial variability by the density of the measurements. In particular the spatial variability can be used to predict the detection limit of changes in soil properties at the field scale.

Task 3.4 Performance of techniques and collation of soil characteristics

The geophysical techniques were interpreted in terms of their ability to map dynamic soil properties identified as common criteria for delineating soils at risk of C decline, compaction and erosion. For each tested technique the performance evaluation consisted in measuring the gap between the estimated soil properties and those observed in the field or stored in existing soil data bases. Special attention was given to the spatial patterns of errors and uncertainties inherent to the geophysical techniques.

For task 3.1, we reported all the experiments that have been conducted on real test sites to evaluate the proposed methodology (D3.2). Test sites were identified as Luxembourg (LU), Mugello (IT) and Zala (HU). For each geophysical method, the experimental conditions, data acquisitions, validation points and produced maps were presented (D3.2). The optimal combination of petrophysical parameters were used to describe the aforementioned soil properties. The inference functions and fusion techniques developed in WP 2 were applied to the field conditions of the different test sites. Where possible geo-referenced data sets and were used for calibration and validation of the geophysical techniques. The experimental conditions, the results and the costs of the experiments and measurements for each geophysical method (Hyperspectral, GPR, EMI, Geoelectric, Seismic), in terms of man-day, were reported in D3.3 (Table 2).

Localization <i>Site coordinator</i>	Soil properties to be investigated	Techniques applied on the sites	Site characteristics	Associated Soil types (WRB)	Obtained results
Luxembourg-LU <i>UCL</i>	C content Density/Stiffness Hydro. Prop. Soil depth	Hyperspectral Magnetism Geoelectric/EM GPR	Southern Belgium/Luxembourg: atlantic area Intensive agriculture Airborne & field data available	UMBRISOL (Hyperdistric) CAMBISOLS ANTHROSOL	C content map Soil depth map Water content map Clay content map Stone content
Mugello-IT <i>UNIFI</i>	C content Soil depth	Hyperspectral Seismic GPR/EM Geoelectric	Mediterranean area Traditional agriculture Soil database available (OM, erosion model)	Calcaric REGOSOL	C content map Soil depth map Water content map Clay content map
Zala-HU <i>UPA</i>	Water content	Geoelectric	Western Hungary: continental area Intensive & traditional agriculture	Haplic CAMBISOL, Haplic LUVISOL (majority), arenic LUVISOL, FLUVISOL	Water variability on time

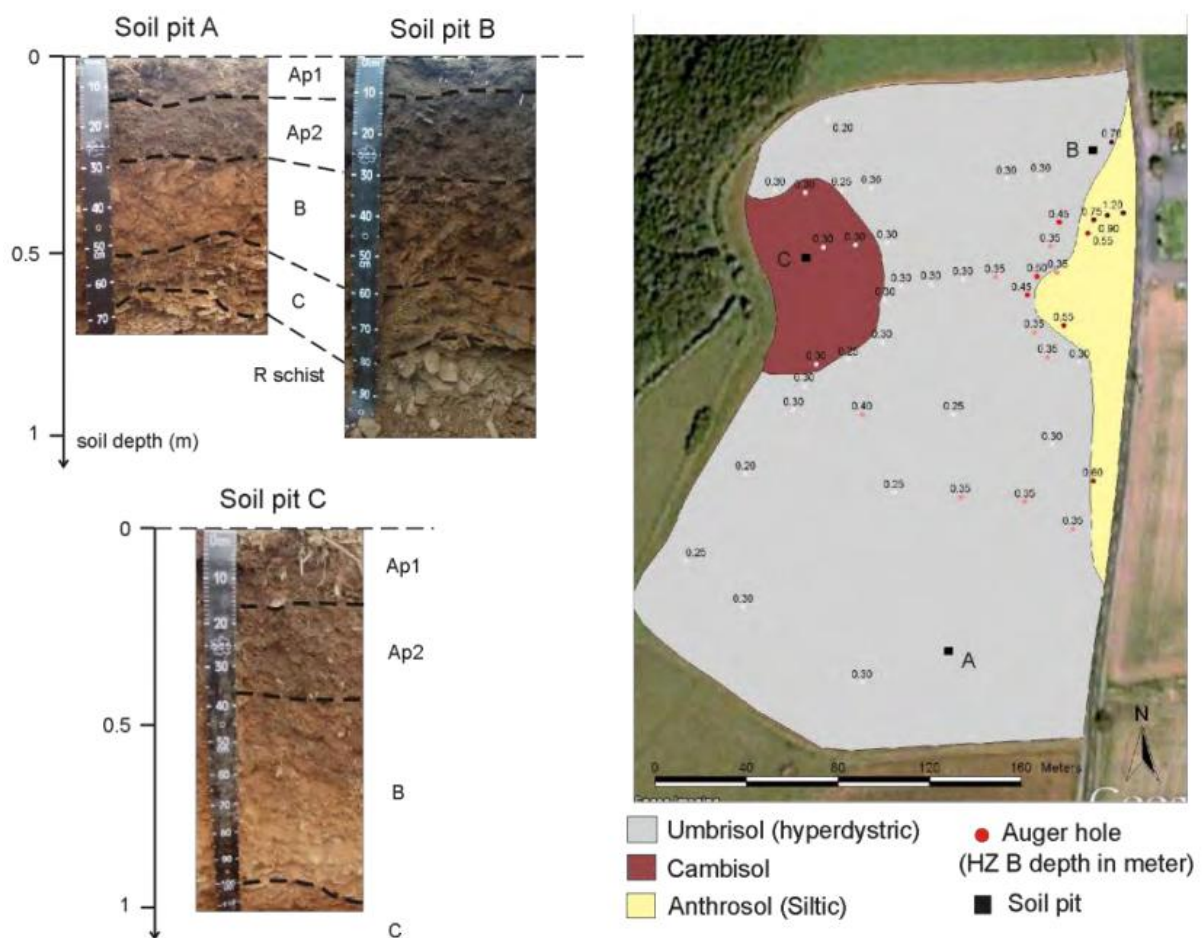
Table 2 : Test sites and their characteristics (Area's typologies are from the "Indicative map of the European biogeographical regions", 2005).

For Task 3.3 we used the general workflow for estimating soil property maps from geophysical signals (Figure 11). Due to different constraints coming from local field measuring contexts, i.e., soil heterogeneity, surface conditions such as roughness, particular physical properties unfavourable to one or several geophysical methods, the theoretical workflow has been modified so that it corresponds now to what it can be really obtained from our methodologies. This new workflow starts with the different techniques (seismic, geoelectric, GPR, EMI, hyperspectral) validated during the project and describes the main

processing levels (inversion, calibration, interpolation). The results are presented as two kinds of maps: the first ones derived directly from the data processing (soil thickness, water content, different clay content maps, surface C content), the second ones are a combination of the previous ones and give the highest level of information (clay content map, C stock map). For task 3.4 the performance of the techniques was evaluated on the accuracy and the level of spatial detail of the maps as well as on the cost of the techniques in terms of labour.

Significant results

The first parcel is situated in the Oësling hills in the north part of the Grand Duchy of Luxembourg with a mean altitude of 450 m. The soils were developed on schist materials partly interbedded with phyllites. Three soil pits were dug in order to describe and analyse soil characteristics. The spatial pattern of soils in this parcel was described with 50 additional auger holes. Three main soil units were found and delimited (*Figure 12*).



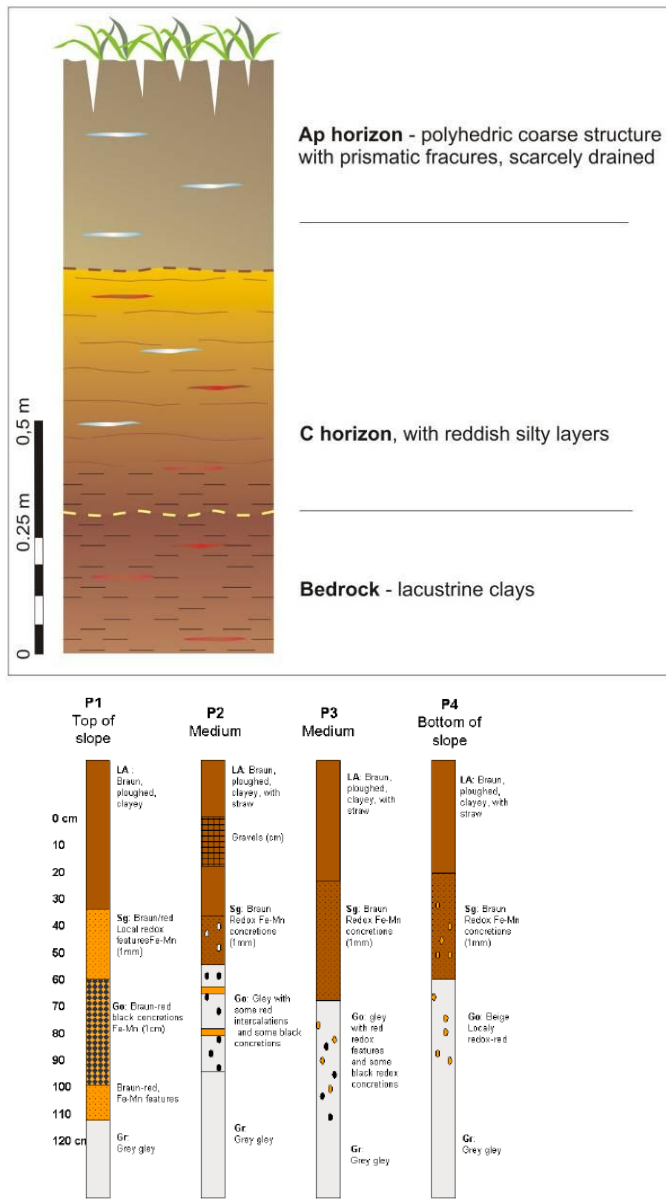


Figure 13: Soils on the Mugello site with the variation of the profiles along the slope in the left hand panel

For the Zala site (Hungary) a large database exists that covers a large area of cultivated fields (about 10 000 ha total). On each of these fields a point was sampled (soil type, water content, pH, etc.). From these sampled locations, a detailed soil map was constructed. However, the points were at least about a 100 m and at most 400 m apart. Consequently it was difficult to infer exact limits and their geometry between the different soil units using only geo-statistical tools. In such a case, the use of geophysical mapping and /or profiling is highly interesting, provided the geophysical measurements can yield information that is relevant for inferring soil properties that are of interest for agricultural needs. Detailed resistivity (and IP) measurements along fixed lines in 2D or 3D were provided using the Abem Terrameter LS and small electrode spacing of 0.5 m or even 0.25 m. Such small spacing was necessary to obtain a good resolution over the soil (down to max 1.5 m).

A) First order maps (tasks 3.3 and 3.4)

According to Figure 11, the first order maps was derived directly from the data processing (soil thickness, water content, different clay content maps, surface C content). Examples of soil thickness in Luxembourg, effective clay content in Mugello and water content in

Luxembourg are given below, while a full report of the geophysical techniques applied in the field is given in deliverable D3.2 and the maps including the uncertainty and performance are given in deliverable D3.3.

Soil thickness map

The map of the difference between RW limit (transition between sub horizontal and horizontal schistosity) depth from MASW and from the validation penetrometer data set allows analyzing the spatial variations of the misfit between the prediction and the validation data set. The prediction error vary between ~ -20 cm and ~ 20 cm. Isolated positive error spots (brown colours in *Figure 14*) can be considered as singular values, probably due to a bad picking of the RW limit horizon on the seismic section. For those points, it would be judicious to reiterate one part of the processing workflow. On the other side, we observe that the negative error cloud is concentrated in the area of lowest RW limit depth (eastern area). As a matter of fact, very thin soils (less than ~ 50 to 70 cm) are a limitation in terms of resolution for the seismic method.

The Digisoil seismic system was run on the field by two operators during two days; another day was dedicated to penetrometer measurements and trench observations. This implies that a consequent part of the spatial resolution in predicting soil depth is due to acquisition parameters. For example, it would be too expensive and too long to realize a seismic survey with an excessively reduced shot interval. In the current state, the performance of the system is about 0.75 Ha per day with a 4 m shot interval and 20 m between seismic lines. A linear regression between the RW limit depth predicted using the MASW methodology and from the validation penetrometer data set at the location of the penetrometer soundings. A significant correlation is observed between these two variables ($R^2 = 0.6255$). This means that $\sim 62\%$ of the real RW limit depth should be explained using this linear regression obtained using the MASW methodology.

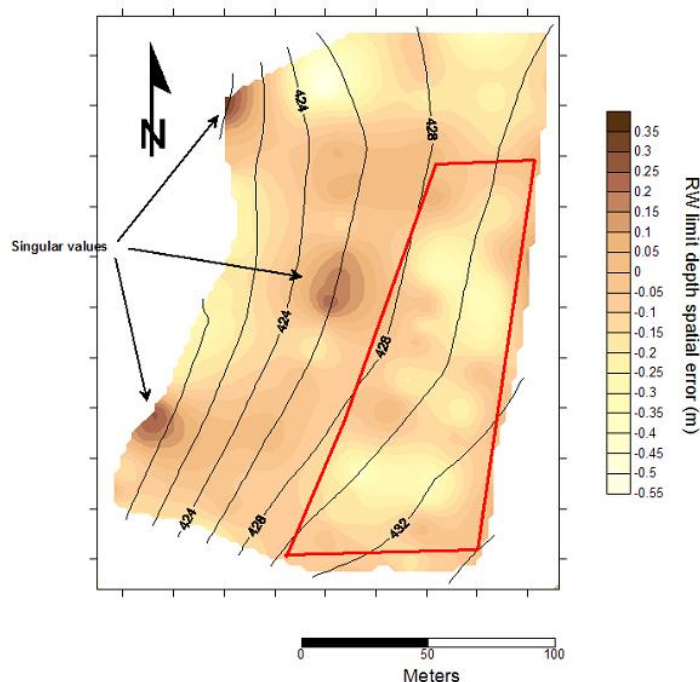


Figure 14: Map of the RW limit depth spatial error obtained calculating the difference between RW limit depth from MASW and from the penetrometer validation data set.

Effective clay content map

The procedure described hereafter allowed obtaining a map of clay content of bare topsoils from airborne hyperspectral images, using the continuum removal technique (Clark and Roush, 1984). This procedure is based on the fact that the depth of an absorption feature is strongly related to the abundance of the absorbing material. Continuum removal normalizes reflectance spectra with the aim of allowing a direct comparison among absorption features from a common baseline, minimizing the effect of different scales or observation conditions.

and assuming that no other material has strong absorption features around that specific wavelength. After CR the absorption peak depth at a certain wavelength is calculated and related to the atomic group responsible for the spectral feature. Clay content and mineralogy influence the short wave infrared portion of the spectrum (1300-2500 nm), but only the peak at 2210 nm can be detected in airborne sensors spectra, which are affected by atmospheric absorption bands (*Figure 15*).

The clay content map deduced from hyperspectral data was compared with the interpolated laboratory values map of the total clay mineral concentration, obtained using the Inverse Distance Weighting algorithm, for validation. The general trend, described in the previous paragraph, can be retrieved in this second map, showing a good agreement between the predicted and the observed clay distribution tendency. Correlation between the two variables is satisfactory ($R^2 = 0.599$); as a consequence, our model can explain about 60% of actual clay content in the topsoils.

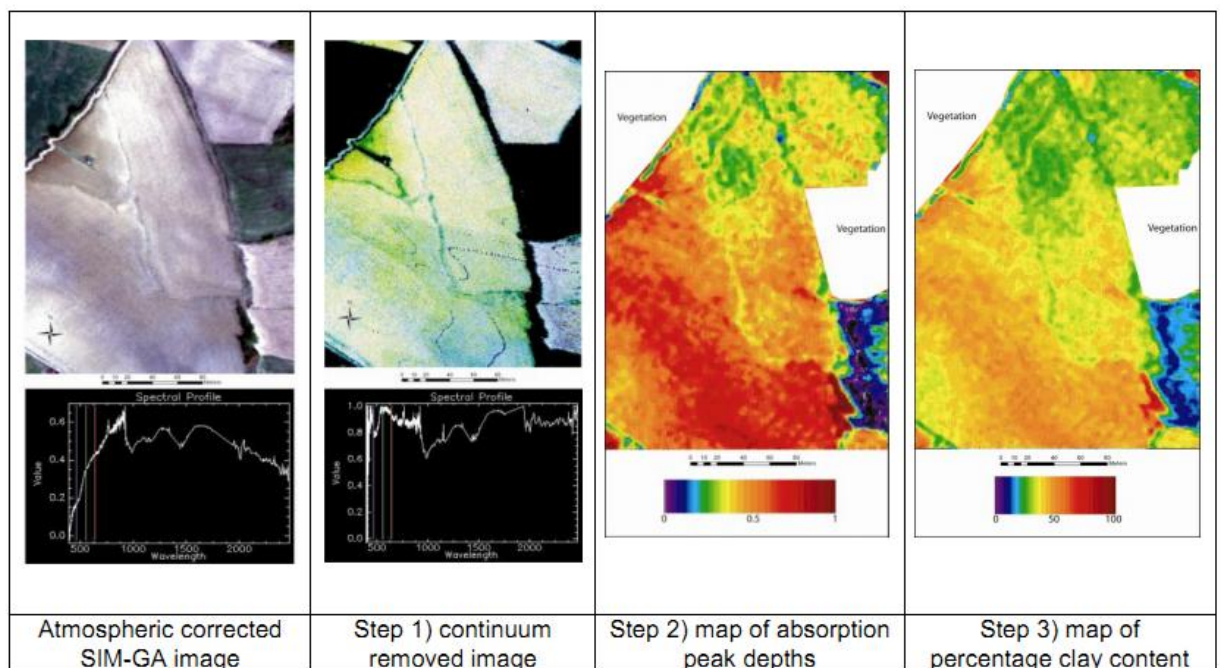


Figure 15: From acquisition to inversion of hyperspectral data

Water content map

Off- and on-ground ground penetrating radar (GPR) surveys were carried out at the Luxembourg site during different weather conditions: dry and wet. In the dry condition, 11 transects were performed with about 1300 traces for off-ground and 14000 traces for on-ground over ~5 ha field. In the wet conditions 13 transects were performed with about 1700 traces for off-ground and about 24500 traces for on-ground. Soil core sampling was carried out at 30 locations over the entire field close to the GPR transects for ground-truth volumetric water content measurements at different depths (0-10, 10-20, 20-30, 30-40, and 40-50 cm). Three of these ground-truth points were sampled during the dry day while sampling at the other 27 locations was performed under wet soil conditions. Applying the STA method to on-ground measurements and surface-reflection inversion to off-ground measurements allowed retrieving the soil dielectric permittivity from each trace. Then, the soil volumetric water content estimates from Topp's equation were interpolated over the entire field using kriging (*Figure 16*). It is worth noting that the off-ground derived map represents only the surface moisture (top ~2-3 cm). The characterization depth for the on-ground map is difficult to specify accurately as it depends on both the operating center frequency and soil moisture. In our case, the characterization depth is expected to be around 30 cm for the dry soil and around 10 cm for the wet conditions.

In order to quantify the error between the 0-10 cm depth ground-truth soil moisture and both GPR derived water content, we used the nearest neighbour of GPR data to the location of ground-truth data. Then linear regressions were used to analyze the relationships between the two variables. The RMSE is about 3.6% for off-ground GPR and 4.9% for on-ground GPR related to the best fit line. Discrepancies between ground-truth measurements and GPR soil water content estimates may arise for several reasons. First, a part of the differences would result from the contrasted characterization depths and scales of GPR compared with ground-truth measurements (100 cm³ cylinders). Furthermore, while GPR surveys were completed within about one hour and a half, soil core sampling over the entire field took one complete day and soil water content is likely to vary during that time as a result of infiltration, especially within the hours following a rain event as it is the case for this field campaign. Moreover, infiltration is likely to evolve spatially as a result of spatial variation of topography and clay content over the field area.

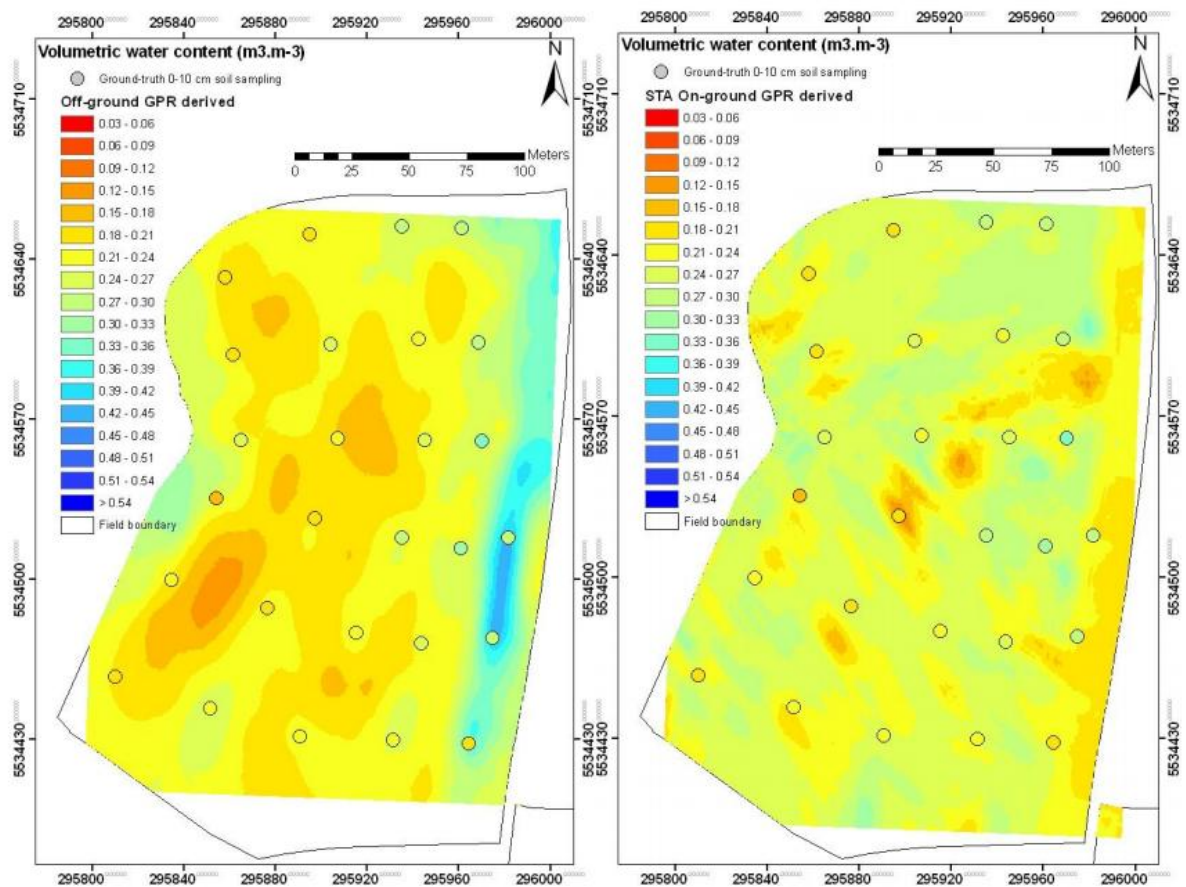


Figure 16: Wet condition soil moisture maps derived by both off- and on-ground GPR techniques compared with ground truths in the top 10 cm.

For proper high-resolution (1 m) mapping of soil properties, GPR measurements should be carried out at a velocity lower than 2 m/s. On the Luxembourg site, the average velocity of the platform during the measurements was 1.9 m/s. Therefore, each survey of the entire field took between half an hour and one hour for one person.

B) Second order maps (tasks 3.3 and 3.4)

The second order maps are a combination of the first order ones and give the highest level of information (clay content map, C stock map). A full description of the maps including their uncertainty and performance is given in deliverable D 3.3.

Soil organic carbon (SOC) stock map

The SOC stock (Mg ha^{-1}) is calculated from the SOC content (C , g kg^{-1}), the bulk density (BD , g cm^{-3}), the rock fragment content by mass (RM , dimensionless) and the thickness of the layer considered (d , m).

$$SOC = C * BD * (1 - Rm) * d * 10$$

The SOC stock required a compilation of soil property maps in order to be able to calculate the SOC stock equation for each pixel. We have chosen to represent the SOC stock for the pixels (2.6 by 2.6 m) of the airborne hyperspectral image acquired by the AHS 160 sensor. The processing of the signals required to determine the individual soil properties have been explained elsewhere (C content: D3.2; bulk density: D3.3; stone content: D3.2; soil depth: D3.3). The map of the SOC stocks of the 0-20 cm topsoil (Figure 3.7) corresponds to the first plough layer (AP1: 0-10 cm) and half the thickness of the second plough layer (AP2: 10-30 cm) as identified in the pedologic survey (D3.2). As this horizon is every year well mixed, there are no vertical gradients in SOC content, stone content or bulk density. Hence, mean values of SOC content (0-20 cm), stone content and bulk density (0-30 cm) were used to calibrate the geophysical signals. In general, The SOC stock of the plough layer decreases from 70 Mg ha^{-1} in the northern part of the field to 20 Mg ha^{-1} on the southwestern margin. The low values on the northeastern field border are probably an artefact. According to the pedologic report, this is an anthropogenic area with a low stone content. Unfortunately, the stone content cannot be estimated for values below 20 %, and the resistivity erroneously indicated very high stone contents. The residuals for the validation points also indicate the largest errors in SOC stocks for this anthropogenic unit (points 4, 9 and 11, Figure 17).

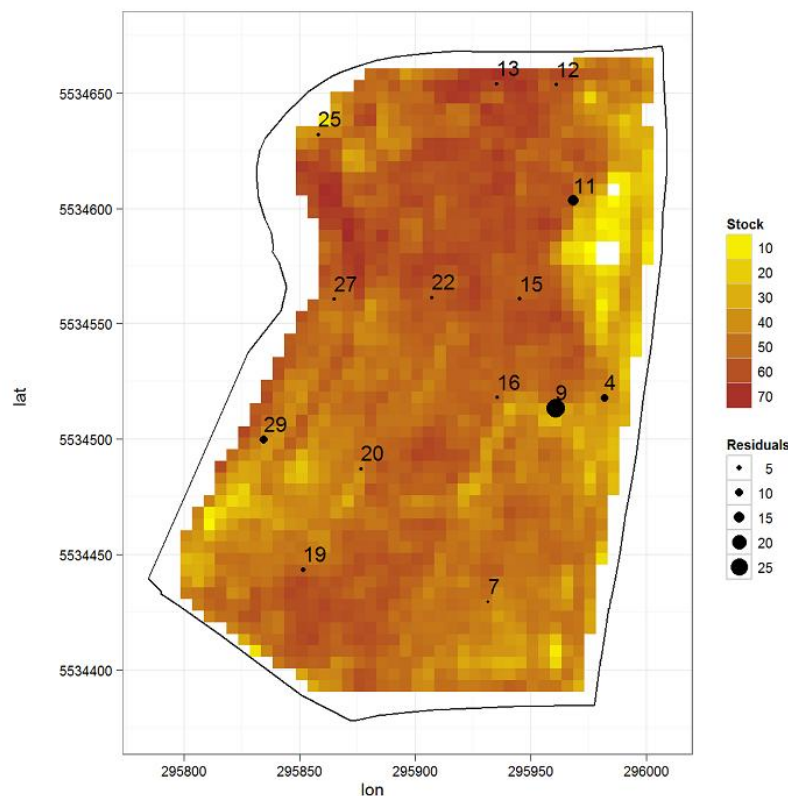


Figure 17: Map of the SOC stocks of the upper 20 cm soil layer. The values and residuals are expressed in Mg ha^{-1} . Point numbers refer to the validation points.

In general, the SOC stock (0-20 cm) in each pixel was reasonable well predicted with an R^2 of 0.3 and an RMSE of 9.41 Mg ha^{-1} . As already discussed above, the prediction would considerably improve when the anthropogenic unit would be excluded from the SOC stock map. Hyperspectral remote sensing using the AHS160 airborne sensor provided the SOC signal for all bare cropland fields in a 60 by 10 km flight line taking 2 hours flight time. It is obvious that a large number of fields should be analysed for cost efficiency of such flight campaigns. The combination of hypespectral remote sensing with geo-electric signals was used to produce the SOC stock, and therefore the costs of the different techniques should be

added up. In order to calculate the SOC stock for the entire field, the variance was estimated from the semivariogram. Given the number of pixels (1692), the mean value of the predicted SOC stock in the upper 20 cm is thus $48.62 \pm 0.56 \text{ Mg C ha}^{-1}$, while the SOC stock (0-20 cm) calculated from the 30 calibration/validation points results in a value of $51.6 \pm 2.37 \text{ Mg C ha}^{-1}$. The slightly lower predicted SOC stock is probably due to the poor prediction of the stone content in the anthropogenic unit, as illustrated by the high residuals in points 4, 9 and 11 (Figure 17).

WP4 – Evaluation of developed technologies and impact for the society

Context

The success of any technology lies mainly in its ability to cater for the needs of the intended users and to do so in a cost effective way. With respect to this, WP4, titled “Evaluation of developed technologies and impact for the society”, aimed to evaluate the impact of the developed techniques by investigating their relevance to the end-user needs, the technical feasibility and the cost effectiveness.

WP4 comprised the following three tasks:

- **Task 4.1 Evaluation with respect to “end-user” needs**

This task involved the identification of potential users, their intended use of the technology and the analysis of their preferences (in economic terms) for the various technology features and services

- **Tasks 4.2-3: Evaluation with respect to the technical feasibility and to the cost effectiveness**

They aimed to calculate the costs of producing and operating the technology and compare these costs with the economic benefits, measured in Task 4.1

The work for Task 4.1 has drawn on and significantly expanded on the work undertaken during the first period. It involved carrying out a second and more detailed survey of potential users in order to assess their economic preferences for various configurations of the proposed soil mapping technologies by deriving estimates of end-users’ willingness to pay for the various map features. The survey was carried out in the form of an online questionnaire, administered to a large number of stakeholders in the wider soil community.

For Task 4.3, an extensive costing exercise was undertaken, whereby the costs associated with the key elements of the various field trials were recorded. Consequently, the generated cost estimates were compared with the willingness to pay estimates in order to arrive to an understanding of the maps’ economic potential.

Task 4.2 has taken a close look at the various techniques employed as well the produced outputs in order to assess the technological readiness and maturity of the developed technologies.

Significant results

Task 4.1

The purpose of the survey has been to identify potential end-users and assess their needs and preferences with regard to the features of the DIGISOIL mapping tool and to produce an estimate of the maps’ economic value, expressed in terms of end-users’ willingness to pay for the maps as a whole but also for specific map features. A previous more limited survey indicated that the bulk of potential users were interested in the acquisition of soil information in the form of digital soil maps, rather than the purchase of the various equipments and software for self-use. The survey began by asking questions on respondents’ line of work and on their intended use of the mapping tool. Figure 18 shows the percentage of respondents falling in the various categories chosen for each question.

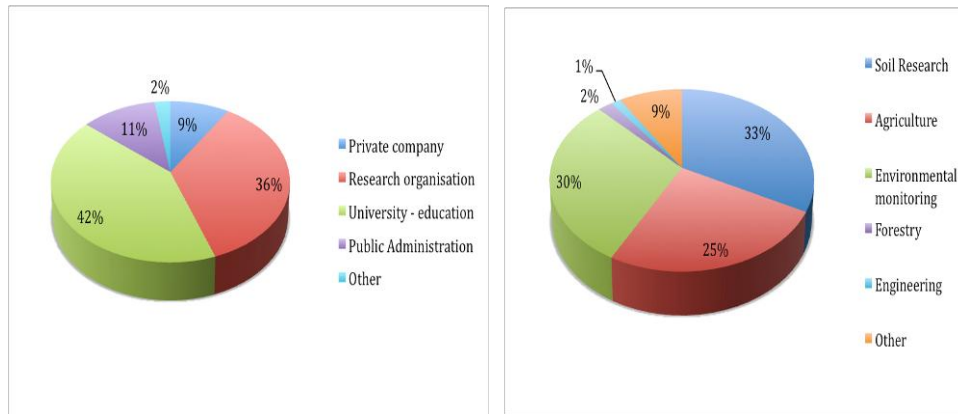


Figure 18: Type of organization and intended use

These figures provide a picture of who are the main target end-users and what is their intended use of the mapping tool. As these figures show, the overwhelming majority of the potential end users come from the research arena, be it a university (42%) or another type of research institute (36%). The third largest group of potential end-users represents public administration entities (11%), followed by the private sector (9%), such as agribusiness companies and consultancies. In terms of the intended use of the DSM, the bulk of the responses are divided roughly equally amongst pure soil research (33%), agriculture (25%) and environmental monitoring (30%).

Besides this information, a choice experiment was carried out. In the choice experiment, respondents were asked to evaluate alternative map versions with regard to varying levels of map resolution and measurement accuracy of the following soil properties: soil depth, bulk density, carbon content, water content and clay content, which are the main soil properties estimated by the techniques developed under DIGISOIL. Measurement accuracy was defined in terms of percentage deviation from the true value of a soil property measured. So, for instance, a map might be capable of displaying carbon content with $\pm 5\%$ accuracy. In addition to the soil properties estimated by the mapping tool, the option of providing indicators of soil degradation has been included as an extra feature of the various map versions.

The inclusion of a “price” attribute as a feature of each map version means that respondents are required to make tradeoffs between better map quality (this being described by higher levels of spatial resolution, measurement accuracy and inclusion of degradation indicators) and higher cost of purchasing the map. Analysis of the series of choices made by respondents reveals their preferences in terms of making tradeoffs between map features. In other words, it allows measuring how much of one feature they are willing to give up in order to gain a bit more of another. Because one of the evaluated features is price, the tradeoffs reveal respondents’ average willingness to pay for different levels of provision of each of the other features. In addition to the design attributes, respondents’ type of employment and their intended use of the mapping tool were assumed to influence choices. Thus, they were included in the data analysis as dummy variables, interacting with the main attributes. *Table 3* presents the willingness to pay estimates for each one of the hypothetical map features.

Attribute	WTP	Attribute	WTP
Map Resolution	183€	Water Content	198€
Soil Depth	157€	Clay Content	264€
Bulk Density	210€	Soil Degradation Indicators	811€

Table 3: WTP for the several features of the DIGISOIL mapping tool

The way to interpret the above numbers is this: each number represents the average WTP for obtaining an extra level of the respective attribute. For instance, for the measurement of carbon content, the average respondent would be willing to pay 263€ for obtaining a low-accuracy measurement. In order to have a measurement of high accuracy for the carbon content respondents would be willing to pay 789€ (3 times 263€). The same applies for the other features of the DIGISOIL mapping tool, such as map resolution and inclusion of degradation indicators. It is evident from these WTP figures that the feature of the DIGISOIL mapping tool that is most highly valued by respondents is the provision of degradation indicators. By extension, it is possible to calculate the overall WTP for complete alternative versions of the mapping tool. For instance, it is possible to calculate respondents' WTP for a high-resolution map, with high measurement accuracy for all the soil properties and with soil degradation indicators included. In the case of the best possible map version, (the one described above) the WTP is calculated to be 3570€/ha. For a medium resolution map, with medium accuracy and degradation indicators, WTP would be 2270€.

In conclusion, the survey has helped paint a picture of who the potential end-users may be and what purpose they would want to use the DIGISOIL maps for. Further analysis of the survey results has shown that there is a positive and significant economic value associated with the use of DIGISOIL's mapping tool which, for a high-definition, high-accuracy map that includes indicators of soil degradation, could be as high as 3570. Moreover, end-users' WTP for individual features of the maps has been estimated, pointing to a particularly strong preference for the inclusion of soil degradation indicators. Unfortunately, the determinants of respondents' choices have not been identified, as the type of employment and intended use of the maps did not seem to have any meaningful effects on choice. If indeed there were such effects, ability to detect them would have helped better understand respondents' choice patterns and consequently help enhance the development of the mapping tool in order to better meet end-users' needs. Nevertheless, the knowledge generated by this research with regard to the economic value of the DIGISOIL's mapping tool is very useful because it provides valuable input for the task of estimating the cost-effectiveness of this technology and thus determining its economic viability.

Task 4.2

This task has looked at the usefulness of the concept and the approach of the project in relation to its receivers. With a focus on the end-user needs, the technical maturity of the output was analyzed. The approach of the project as well as reported results is looked at. To assess the procedures as reported the technical readiness level (TRL; *Figure 19*) method has been applied. It indicates that a geophysical "multi-functional" tool as suggested by Digisoil has a lot of potential in contributing to the soil information database. At the current level it is the processed result that shows the highest degree of maturity with both the first order maps and second order compiled maps results in detailed continuous maps that can be used for further decision making.

The added dimension of geophysics will allow that a lot of point-based soil information from, for example, soil samples can be enhanced into more continuous information flow for the generation of soil property maps. This will increase the knowledge base for the end users of the product.

It is clear from the report of the work in the Digisoil project that further development is needed before a geophysical multi-functional tool will be available on the market. As mentioned earlier the output is of great interest but there is still need for a comparably high competence level to run and interpret the measurements before they can be used as a base for the creation of second order maps. Both the hardware platform and the processing software need further development before a useful product is available.

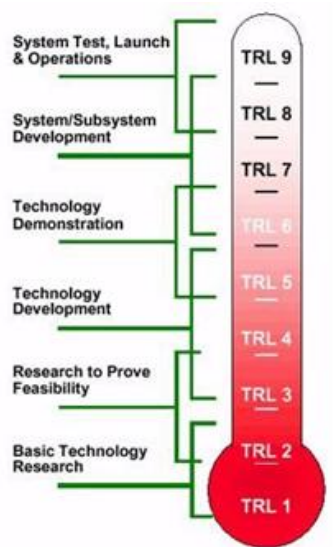


Figure 19: TRL levels . Digisoil reach approximately Level 7

It should be kept in mind that the greatest interest has so far been documented to be towards the processed and compiled second order maps rather than making the measurements. Thus the level of development of a multi-functional solution should, at this point, maybe be geared towards a user category that has both the competence to run the surveys and to compile the maps, with a goal to supply the information that the end users are interested in.

Task 4.3

Task 4.3 has undertaken a cost estimation of the various activities undertaken during the project phase that involved conducting fieldwork and analyzing the data for the purpose of producing maps of the selected soil properties. Furthermore, in order to determine cost-efficiency, Task 4.3 conducted a cost-benefit analysis (CBA) of DIGISOIL's mapping tool as a potential new product by coupling the cost information with the WTP information generated by Task 4.1. The following tables summarize the various cost findings. Table 4 depicts the cost structure of the three ground-based geophysical techniques while Table 5 refers to the cost structure of the airborne technique employed.

	Fieldwork		Data Analysis		Total
	Equipment	Labour	Equipment	Labour	
Seismic	53170 €	2175 €	3300 €	1185 €	59830 €
Geoelectric	6500 €	1102 €	22400 €	2590 €	32592 €
GPR/EMI	108000 €	263 €	15400 €	4200 €	127863 €
Total	167670 €	3540 €	41100 €	7975 €	220285 €

Table 4. Summary costs for geophysical fieldwork & data analysis

	Fieldwork		Data Analysis		Total
	Equipment	Labour	Equipment	Labour	
Hyperspectral	85840 €	3180 €	38400 €	29300 €	156720 €

Table 5. Summary costs for HS operation & mapping

These cost figures they need to be interpreted and put in the right context by making certain points and assumptions that will make them comparable to the estimated WTP benefits:

- The estimated WTP is on a per-hectare basis.
- The area covered by the ground-based techniques in Luxembourg is about 6 hectares.
- The area covered by the airborne hypespectral operation in Mugello is about 130 hectares but the mapped area and the area where soil sampling and analysis was carried out is just over 5 hectares.

- Most of the equipment/software used for both ground-based and airborne operations has been purchased. Exceptions are the SIMGA sensor, the aircraft used and the MUCEP device, which were leased for one day. The purchase price for a system similar to SIMGA is about 250-300K €, while for an aircraft of similar capabilities it is 70K €. The MUCEP device is currently not on sale but only leased out.
- Capital (physical equipment & software) depreciates, and according to the depreciation rate applied, different capital life spans are assumed. An optimistic depreciation rate is 10% for physical capital, implying a time span of 10 years. Computers and software, however, depreciate considerably faster, as newer and more advanced versions spring up regularly, rendering existing ones increasingly obsolete. Thus, with an optimistic 20% rate, software and computer life span is estimated to be 5 years.
- A maximum of 20 operations can be performed each year.

On this basis, a WTP compliance analysis is tried in order to perform a “commercial maturity” evaluation of DIGISOIL technologies and final products (soil parameter maps). In the upper part of the Table 6, the WTP/ha values, as estimated and described in D4.1, are reported both for low quality and high quality maps in terms of map resolution and accuracy. In the middle part of the table, the different technology costs and instrument configurations for different maps are enhanced. For each kind of map the total cost for the required instrument configuration is also reported. The lower part of the table shows the results of the compliance (maturity) analysis for low quality and high quality maps in terms of WTP/Cost (%).

		<i>WTP/ha</i>						
		Map	Soil	Bulk	Carbon	Water	Clay	Degradation
<i>Low quality</i>		-	157	210	263	198	264	-
<i>High quality</i>		(183)	471	630	789	594	792	(811)
<i>Technology</i>	<i>Cost/ha</i>							
SISMIC	740		X	X				
GEOEL.	1590			X		X	X	
GPR/EMI	1035		X		X	X		
HYPER	270				X		X	
<i>Total</i>	<i>3635</i>							
	<i>Technology Cost/ha/Map</i>		1775	2330	1305	2625	1860	(9895 = total cost/ha)
	<i>Low Quality Map Maturity</i>		8.8%	9.0%	20.1%	7.5%	14.1%	
	<i>High Quality Map Maturity</i>		26.5%	27.0%	60.4%	22.6%	42.5%	

Table 6. "Commercial maturity" analysis based on cost results and estimated WTP

The cost impact of DIGISOIL technologies is shown in *Figure 20*, where ground geophysical methods show higher costs compared with airborne Hyperspectral technique because the impact on cost/ha of ground and laboratory work is higher than flight management and airborne data processing. The impact of each DIGISOIL technologies expressed in % of the total cost/ha (9895€) is also shown. Observing the diagram seems that these five maps are nearly balanced in terms of costs.

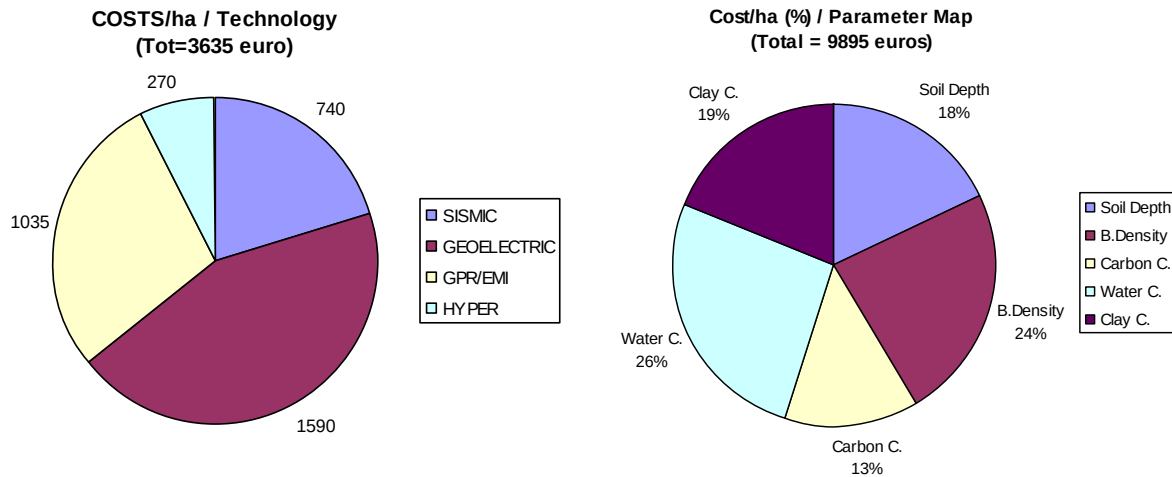


Figure 20: Cost impact of DIGISOIL technologies; Cost impact of DIGISOIL maps

Finally, the compliance (maturity) results shown in the lower part of Table 6 are shown as bar diagram in Figure 21 in order to enhance different maturity level (0-1) for low and high quality maps, as well as the “commercial gap” which results from DIGISOIL study. The business development on digital soil mapping, as well as further technology developments and economic studies will be to bridge this gap up to the full commercial maturity.

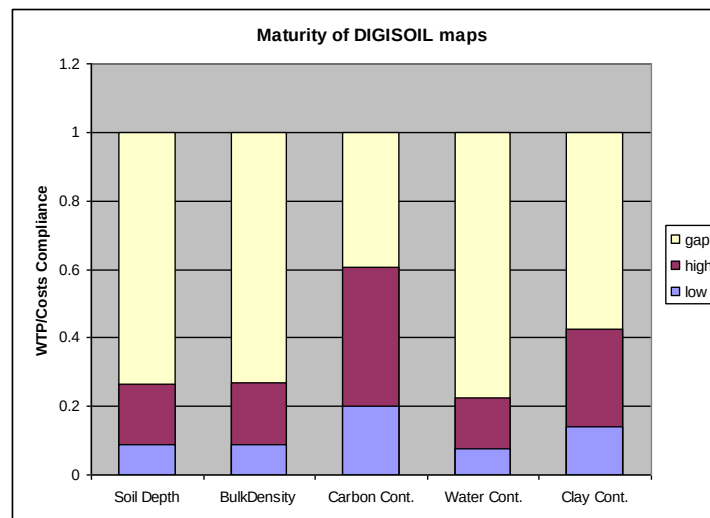


Figure 21: "Commercial maturity" of DIGISOIL maps

The main result of this work is the commercial maturity estimation for low and high quality maps as shown in Figures where:

- The unit cost/ha ranking from (low to high cost) of studied geophysical methods is: 1) Hyperspectral (270€), 2) Seismic (740€), 3) GPR/EMI (1035€), 4) Geoelectric (1590€)
- The maturity ranking of soil maps is 1) Carbon Content (60%), 2) Clay Content (42%), then Bulk Density, Water Content and Soil Depth in the range (23-27%)
- the commercial gap ranges from 77% to 40% for high quality Water Content map and Carbon Content maps respectively.

The “commercial gap” which results from WTP/cost compliance analysis means that further business development on digital soil mapping, as well as further technology developments

and economic studies are needed to bridge this gap up to the full commercial maturity of DIGISOIL products.

WP5 – Synthesis of the results, standardization and exploitation for technological valorisation

Context

The general objective of WP5 was to reformulate scientific results of the project in terms of operational exploitation for future services where soil mapping from geophysical techniques are required. After the completion of 2010 ground activity the specific objective of the WP was the validation of results from different techniques as well as the data fusion up to the fulfilment verification of different functional requirement parameters in order to evaluate their final maturity level for exploitation purposes and operational perspective.

WP5 encompassed three major tasks:

- **Task 5.1. Scientific synthesis of the project**

A concise report on technical activities up to the definition of operating manuals was produced. This report include lists of used equipments, the processing, the study of uncertainties, measurement protocols and sampling strategy.

- **Task 5.2 Technological specifications and guidelines**

Technical specifications of the geophysical system were studied including functional analysis of the system and requirements for main functions.

- **Task 5.3 Operational exploitation**

The potential exploitation of airborne Hyperspectral data for soil mapping was investigated for soil carbon and clay content. Moreover the economical evaluation of the mapping tool on the basis of cost analysis from task 4.3 was carried out.

Significant results

Task 5.1

This task aimed at providing an overall synthesis if the work achieved and results obtained in the course of the project. To sum it up:

- Several geophysical techniques that were carried out in the project are based on positive experiences in the domain, and promise to fulfill the objectives of the project. Electrical and GPR measurements, hyperspectral imagery, and more innovative methods like seismic methods were tested and technically adapted to soil properties mapping. An important output of the project concerned the economic and maturity estimation of such technologies, based on the real experiments carried out on the two DIGISOIL test sites.
- Technical maturity and economic analyses were detailed in D4.1 and D4.2, and were performed on the basis of willingness to pay (WTP) and real cost analysis methods. The main result of this work is the commercial maturity estimation for low and high quality maps where:
- The unit cost/ha ranking from (low to high cost) of studied geophysical methods is: 1) Hyperspectral (270€), 2) Seismic (740€), 3) GPR/EMI (1035€), 4) Geoelectric (1590€)
- The maturity ranking of soil maps is 1) Carbon Content (60%), 2) Clay Content (42%), than Bulk Density, Water Content and Soil Depth in the range (23-27%)
- The commercial gap range from 77% to 40% for high quality Water Content map and Carbon Content maps respectively.

The “commercial gap” which results from WTP/cost compliance analysis means that further business development on digital soil mapping, as well as further technology developments and economic studies are needed to bridge this gap up to the full commercial maturity of DIGISOIL products. This should be particularly the object of future project more oriented toward operational prototypes

Task 5.2

In Deliverable D5.2 constraints for production of geophysical parameters maps and interdependencies between DIGISOIL hierarchical products were studied. Moreover different requirements that structure the generation of the final products were defined (Principal functional requirements, Derived and secondary functional requirements, Non-functional requirements). At the end of this functional analysis a synthetic function chart of DIGISOIL's workflows is provided.

Task 5.3

Deliverable D5.3 deals with operational exploitation for future services of DIGISOIL products. Therefore operations needed to produce the different maps was studied and summarized, either for ground methods and airborne based. In particular for clay mapping based on Hyperspectral airborne data the overall workflow in set-up and the final validated total clay map for the Mugello test field was derived.

Some optimisations and efforts can be saved both for ground geophysics and airborne Hyperspectral operations have been defined and the maturity level for different maps/methods as reported in deliverable D4.3 was also tried in D5.3 for the foreseen optimisations.

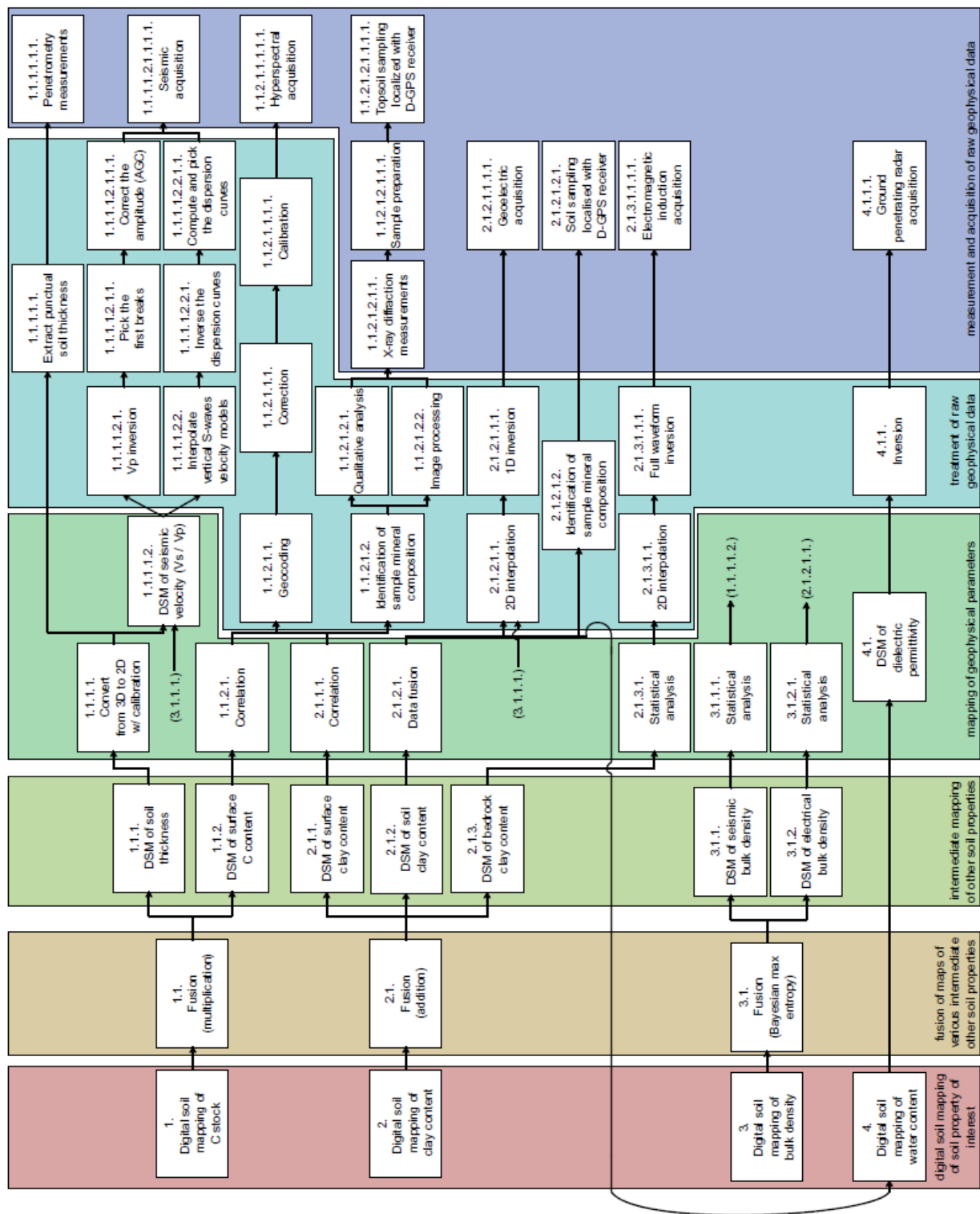


Figure 22. Global function chart (from D5.2)

In this case the high maturity levels can be reached for carbon and clay content mapping in the case of high quality data where both ground and airborne methods are needed, whereas for the other parameters a maturity gap still remain to be filled up with further technological (equipment and SW) improvements to be studied or on the basis of business/commercial strategies. The technical solution of a single airborne Hyperspectral platform able to map C or clay content was particularly studied (*Figure 23*). Compared to costs requested by ground techniques, this solution is better in the scope of end-users willingness to pay. On the other hand, such sensor can only retrieve surface properties with medium spatial resolution (2-5m)

and low ($\pm 10\%$) to medium ($\pm 5\%$) accuracy. To evaluate subsurface information (properties featuring materials below the surface) and to reach an overall high accuracy measurements ($< \pm 5\%$) ground techniques are essential.

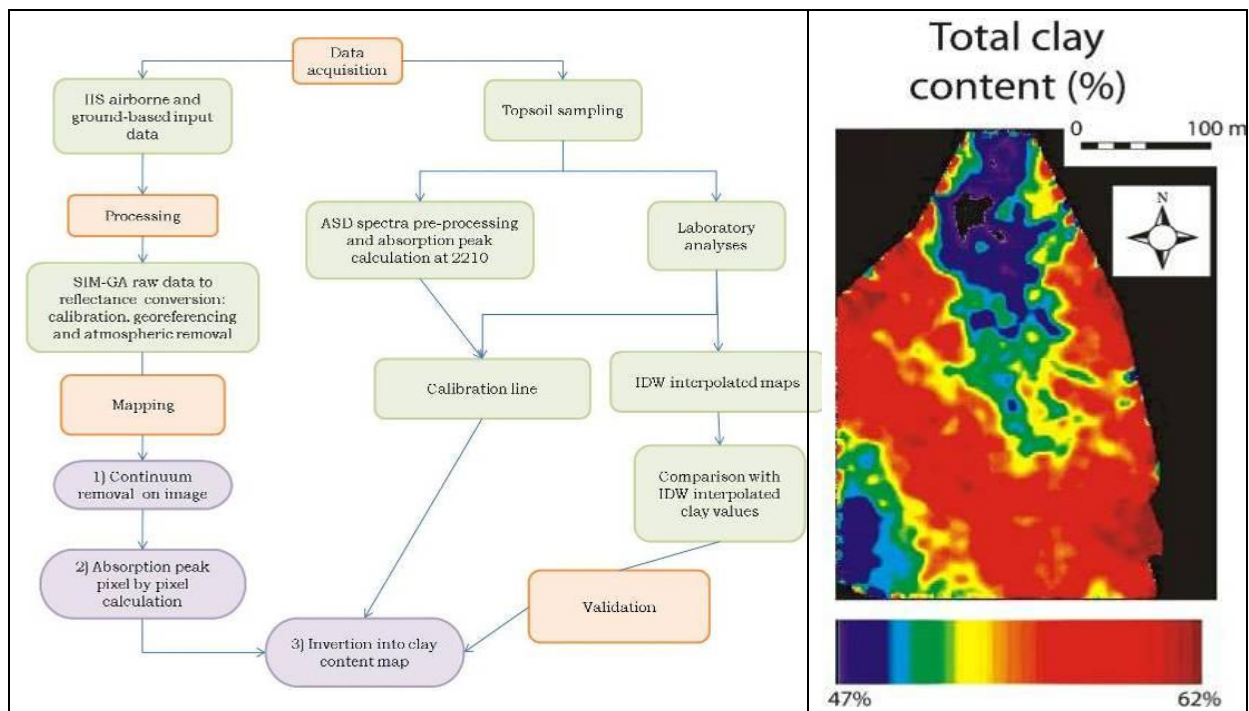


Figure 23. a) Example of overall workflow for clay mapping, b) total clay content map on Mugello test field (from D5.3)

In conclusions, the operational exploitation of the mapping tools realized in the DIGISOIL project reveals that both airborne and ground methods can operate synergically. Depending on the end-users' needs, a minimum part of measurements could involve ground methods – more robust and integrating surface but also subsurface properties – and airborne ones – more efficient to cover large areas for a minimum costs.

Potential impact and main dissemination activities, exploitation of the results

WP6 – Dissemination of results

Context

Work package 6 deals with communications and dissemination activities of the project and will act as an information exchange platform between beneficiaries, EC representatives, stakeholders and future users of the DIGISOIL technology. The objectives of this WP are to construct a well-documented web site, to promote communication between project beneficiaries, EU officers and the project stakeholders and tool users, and to develop resources presenting the scientific outputs of the DIGISOIL project. These objectives are realized within the common dissemination plan decided with the iSoil consortium.

The following table indicates the progress of the different actions related to WP6 (see D6.1)

List of tasks	Task #	Progress	Actions done	Actions in progress
Scientific communications	6.1	100%		
<i>Conferences</i>			92 abstracts	Some abstract
<i>EGU</i>			2008, 2009, 2010, 2011	2012
Scientific publications	6.1	75%		
Rank A publications			33 publications	Some of them
Articles in Books			11 chapters	
Handbook with iSoil	6.1	90%	4 chapters	First draft : end 2011
WEB sites *	6.2			
BRGM management site			Working	
UPA logistic site			Working	
JRC scientific site			Working	
SOILTECH site			Working	
Professional communications	6.3	100%		In preparation for 2011
<i>NOVCARE</i>			2009	
<i>CONSOIL</i>			2010	

Significant results

As described in the D6.1-3, the significant results lie in the following actions:

- Scientific valorisation published in peer reviewed scientific journals, scientific conferences or technical books:
 - 11 book chapters;
 - 33 publications in scientific journals;
 - 92 conference abstracts
- Contributions to the iSoil conferences and handbook
 - Co-organization of scientific sessions with the iSoil consortium (EGU 2008, 2009, 2010, 2011) and participation to iSoil dissemination actions

- 4 chapters in the iSoil handbook
- 3. Professional communications
 - >Technical presentations and professional discussions at two professional oriented conferences (NOVCARE 2009 and CONSOIL 2010).
- 4. Web site development within two servers, one dedicated to the scientific dissemination of the project's results (<http://eusoils.jrc.it/projects/digisoil/index.htm>), the second integrating the different EC projects as a Soil Research Cluster (<http://www.ufz.de/index.php?en=19441>).
- 5. Release of 2 Policy Briefs to support the EC Soil Thematic Strategy.

Address of the website, contacts

<http://eusoils.jrc.ec.europa.eu/projects/digisoil/>

Contact:

Dr. Gilles GRANDJEAN

g.grandjean@brgm.fr

BRGM - French Geological Survey

Service Risques – Risks Division

3 avenue C. Guillemin - BP36009 - 45060 ORLEANS - cedex 2

FRANCE