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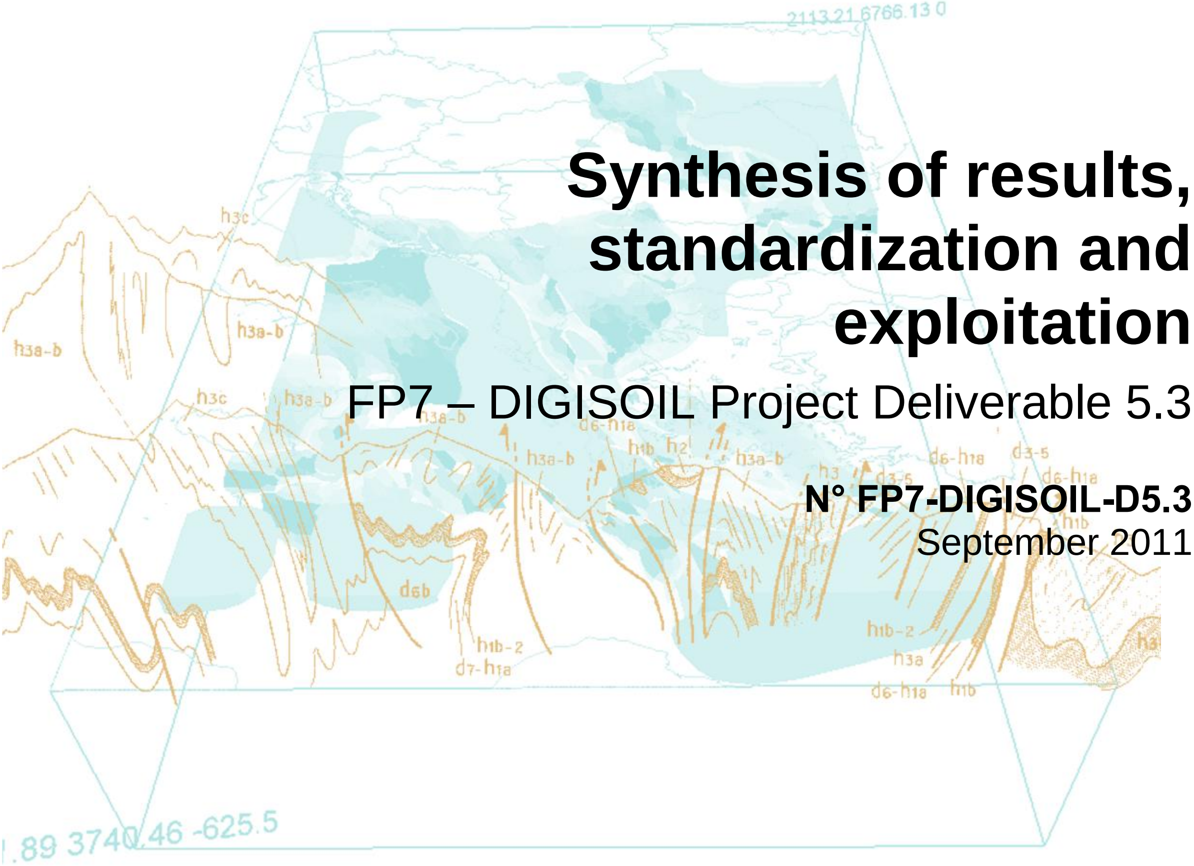

Synthesis of results, standardization and exploitation

FP7 – DIGISOIL Project Deliverable 5.3

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N° FP7-DIGISOIL-D5.3
September 2011

The DIGISOIL project (FP7-ENV-2007-1 N°211523) is financed by the European Commission under the 7th Framework Programme for Research and Technological Development, Area “Environment”, Activity 6.3 “Environmental Technologies”.

Geoscience for a sustainable Earth

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L.Chiarantini (GAV)

Checked by:	**Approved by**:
Name: I.DIafas	Name: G.Grandjean
Date: 19/06/2011	Date:19/06/2011
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Synopsis

This study aimed to deliver a summary of user manual of the DIGISOIL mapping tool. The operations needed to produce the different maps are presented, either for ground methods or airborne ones.

In particular, the technical solution of an airborne platform able to map C or clay content is studied. 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. To evaluate subsurface information (properties featuring materials below the surface) ground techniques are essential.

In conclusions, the operational exploitation of the mapping tools realized in the DIGISOIL project reveals that both airborne and ground methods are necessary to operate. 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.

Contents

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1. Introduction

1.1. THE MAPPING PRODUCT

The DIGISOIL mapping tool is based on two measuring approaches: ground-based and airborne techniques. In the present report we analyse the different solutions that were proposed in the project.

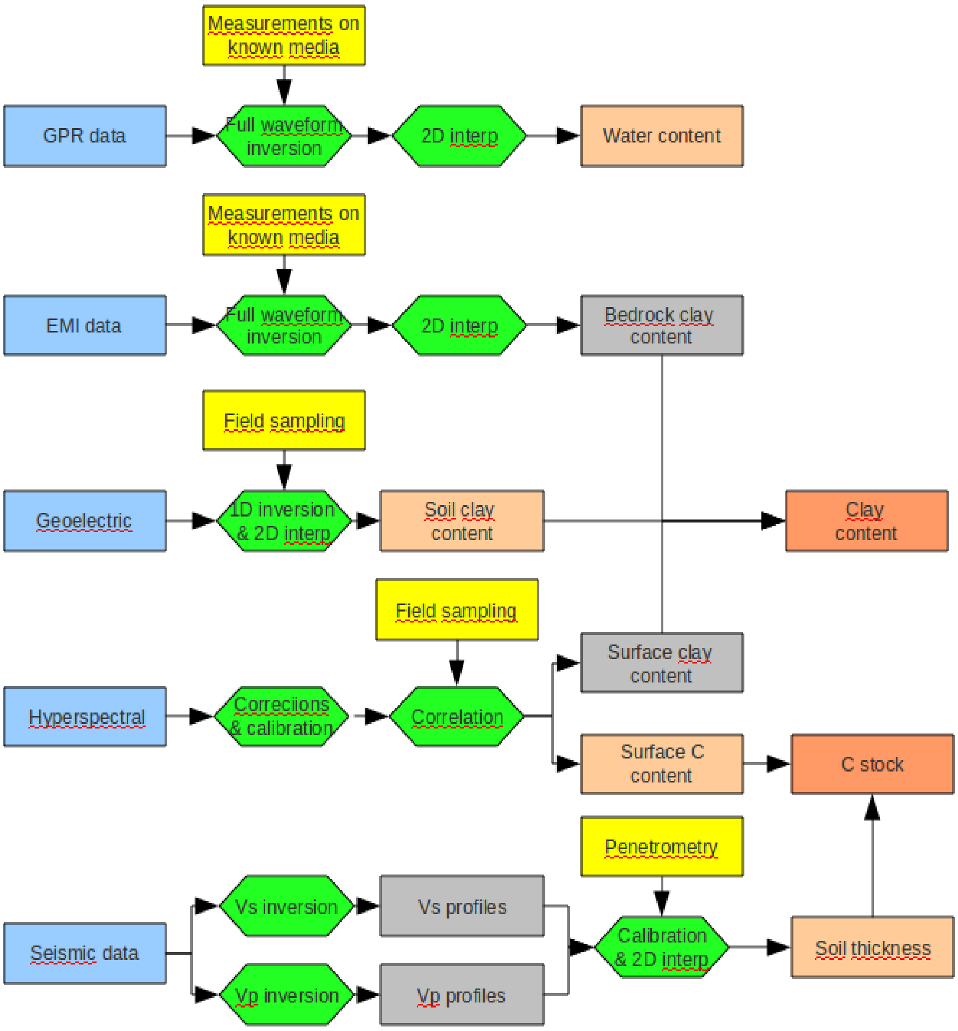


Figure 1 : Synoptic of the DIGISOIL system

Figure 1 shows how the different geophysical methods are used to produce the properties maps. The object of this report is to discern the part of the workflow that is sufficiently mature at a technical and economic point of view.

The first part of the report describes, in a synthetic way, the different tasks and operations necessary to build soil properties from ground-based methods. These methods are interesting in the capacity they have to produce properties maps at high resolution, to sound the soil down to several meter deep, to produce measurements with high signal to noise ratios. On the other hand, the protocols for data acquisition, data calibration and map generation are costly in human works.

The second part is dedicated to airborne sensors. In particular, hyperspectral system flights on a ultra-light aircraft is studied in order to produce C and clay content maps covering large areas. More difficult to operate from a technical point of view, this solution appears to be extremely interesting for decreasing costs.

2. The ground-system documentation

2.1. INTRODUCTION

The DIGISOIL system is composed by different acquisition tools that deliver services for soil properties mapping. In D5.2, the functional analysis enumerated the principal functions, which are coincident with the principal functional requirements:

- F1: digital soil mapping of C stock ➔ airborne
- F2: digital soil mapping of clay content ➔ airborne, ground
- F3: digital soil mapping of bulk density ➔ ground
- F4: digital soil mapping of water content ➔ ground

In the following, we summarize the different operations related to each of ground techniques, identifying the elementary steps necessary to obtain the required final data. The airborne part will be described in more details in the next section.

2.2. GROUND OPERATIONS DESCRIPTION

In this section the following ground techniques are described as parts of the DIGISOIL system:

- Stone or clay content mapping with geoelectric
- Soil thickness and subsurface stiffness mapping with seismics
- Water content mapping with GPR/EMI

The objectives of the following sections are to present, as documentation, the elementary operations necessary to be operated on the field in order to obtain the soil properties maps. More detailed information on sensors, acquisition systems, validation protocols, calibration, etc can be found on previous deliverables of WPs 1 to 3.

2.2.1. Stone/clay content

According to the functions described in Figure 2 (cf. D5.2), the soil clay content is retrieved by achieving the following tasks:

1. Measurement of apparent resistivity along profiles crossing the parcel to be studied; a D-GPS is connected to such measurements;

2. Inversion of apparent resistivity values with a 2 layers model (top soil and bedrock) to obtain real resistivity distributions in the top soil;
3. Spatial interpolation of top soil real resistivity values to obtain a resistivity map;
4. Soil sampling to estimate locally clay content values from laboratory measurements; a D-GPS is used to locate each of measurements;
5. Correlation between inverted real resistivity values and observed clay content ones to produce calibrated clay content maps.

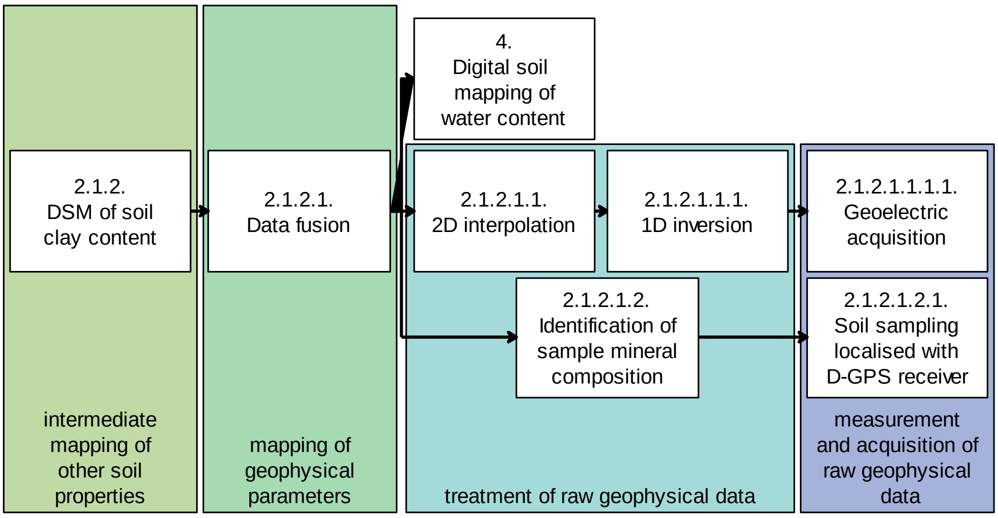


Figure 2 : Soil clay content procedure

2.2.2. Soil thickness/stiffness

According to the functions described in D5.2, the soil thickness and stiffness are retrieved by achieving the following tasks:

1. Acquisition of seismic shots coupled with a D-GPS for localization;
2. Computing of Rayleigh waves dispersion and inversion to obtain S-waves vertical model for which top soil and bedrock values are estimated;
3. Spatial interpolation of top soil real resistivity values to obtain a S-wave map;
4. Local measurement of soil stiffness by penetrometry to obtain Qd variations with depth used for stiffness calibration and thickness estimation; a D-GPS is used to locate each of measurements;
5. Correlation between inverted S-wave values and observed stiffness ones to produce calibrated stiffness maps and soil thickness ones.

2.2.3. Water content

According to the functions described in Figure 3 (cf. D5.2), the soil water content is retrieved by achieving the following tasks:

1. Calibration of GPR and EMI antennas in laboratory;
2. Measurement of GPR/EMI along profiles crossing the parcel to be studied; a D-GPS is connected to such measurements;
3. Spatial interpolation of top soil dielectric permittivity values to obtain a permittivity map;
4. Inversion of GPR/EMI signals using a surface model for which the dielectric constant values are estimated;
5. Estimation of a water content map using a Top's law;

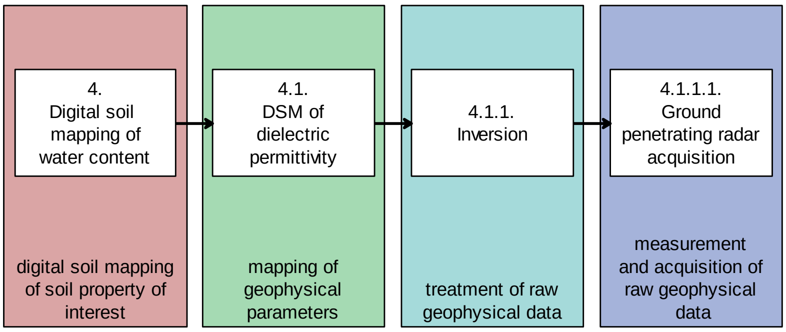


Figure 3 : Water content procedure

2.3. SUMMARY OF COSTS INVOLVED FOR GROUND MEASUREMENTS

In the following table, the costs related to the different ground-based geophysical measurements are averaged for the 3 maps production described above. Note the prices are purely indicative, since they depends on the equipment used, the surface to be explore. In this example, we report the process related to the Luxemburg experiment carried out by partner BRGM, UCL, INRA and ABEM (see Report FPT7-DIGISOIL-D4.3 for details).

	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 €**

Figure 4. Summary of cost analysis for ground geophysical methods

With these indicative costs, not fully compliant with market ones, and knowing the following points:

- The area covered by the ground-based techniques in Luxemburg is about 6 hectares
- Most of the equipment/software used for ground-based operations has been purchased. Exception is the MUCEP device currently not on sale but only leased out for one day.
- Capital (equipment and software) considering a depreciation rate of 10% (physical equipment) and 20% (computers and software) a life span of 10 and 5 years respectively are estimated.
- The number of experiments can reach 20 per year

The averaged costs per hectare for ground soil properties mapping in Luxemburg employing the above mentioned techniques can be calculated as follow:

[160570€ (physical equipment) / 10 years / 20 times + 4000 (MUCEP leased) + 48200€ (software+computers) / 5years / 20 times + 11515€ (labour)] / 5ha= **3360€/ha**

This gives for sounding a parcel of 1 ha: 3360€

Comparing the WTP (willingness to pay) presented in D4.1 with these final averaged costs indicates that some efforts are yet necessary to reach an operational tool able to fit the end-users WTP.

Nevertheless, several tasks can be optimized so that these costs drop drastically to at least the half of the total amount; for example:

- The number of persons operating the 3 systems can be restricted to 3 if the measuring systems are integrated in the same platform;
- For operational works, if the methods are deployed regularly, we could imagine that the correlations between geophysical parameters and soil properties are

better known and don’t required to perform too many analyses. Soil sampling works and related analyses could be reduced.

Another way to increase the system performances lies in the exploitation of additional sensors, able to upscale the results obtained on ground. The use of airborne hyperspectral technique, as proposed in the project, is analyzed in the next section as an efficient solution for upscaling.

3. Hyperspectral aspects

In this part, an overview of hyperspectral aspects is performed in order to analyze if such technique is able to be used for upscalling soil properties (typically C and clay content) toward regional scale.

3.1. THE HYPERSPECTRAL SYSTEM

3.1.1. The AHS system

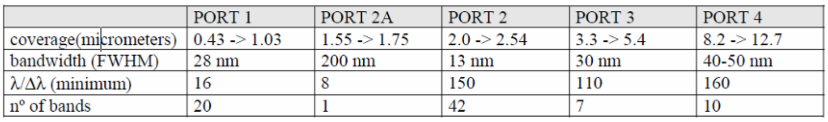
The AHS is an imaging 80-band line-scanner radiometer, built by Sensytech Inc (currently Argon ST, and formerly Daedalus inc.) and purchased by INTA on 2003. This instrument has been installed in the INTA´s aircraft (CASA C-212), and integrated with a GPS/INS POS-AV 410 from Applanix.

The AHS was first flown by INTA on September 2003, and is fully operational from beginning of 2005. It has a design which has very distinct spectral performances depending on the spectral range considered. In the VIS/NIR range, bands are relatively broad (28-30 nm): the coverage is continuous from 0.43 up to 1.0 microns. In the SWIR range, there is an isolated band at 1.6, useful to simulate the corresponding band found in a number of satellite missions. Next, there is a set of continuous, fairly narrow bands (13 nm) between 2.0 and 2.5 microns, which is well suited for soil/geologic studies. In the MIR and TIR ranges, spectral resolution is again high (30 to 50 nm), and the atmospheric windows (3 to 5 microns and 8 to 13 microns) are fully covered. With this spectral features, AHS is best suited for multipurpose studies/campaigns, when a wide range of spectral regions are required, specially if no detailed spectroscopy is required; and, in particular, is a very powerful instrument for thermal remote sensing.

The resulting system is available to the international remote sensing community through specific contractual agreements or based on joint collaborations (website: www.inta.es)

It’s called AHS system the suite of instruments, software tools and procedures used to produce image data from the initial user requirements. The main elements of the AHS system are detailed below.

The INTA platform (figure 1) is a non pressurized cabin, twin engine aircraft Aviocar CASA C-212-200 S/N 270. It has been configured and instrumented as a remote sensing platform by INTA engineers and maintained and operated by an Spanish Air Forces body (Centro Cartográfico del Ejército del Aire, CECAF) through a dedicated agreement. This aircraft is included in the EUFAR consortium (www.eufar.net).



	PORT 1	PORT 2A	PORT 2	PORT 3	PORT 4
coverage(micrometers)	0.43 -> 1.03	1.55 -> 1.75	2.0 -> 2.54	3.3 -> 5.4	8.2 -> 12.7
bandwidth (FWHM)	28 nm	200 nm	13 nm	30 nm	40-50 nm
λ/Δλ (minimum)	16	8	150	110	160
nº of bands	20	1	42	7	10

Optical design	scan mirror plus reflective optics with a single IFOV
FOV(Field Of View)	90º
IFOV(Instantaneous FOV)	2.5 mrad
GSD (Ground Sampling Distance)	2.1 mrad (0.12 degrees)
Scan rates	12.5, 18.75, 25, 35 r.p.s., (corresponding ground sampling distances from 7 to 2 meters)
Digitization precision	12 bits
Samples per scan line	750 pixels/line
Reference sources	two controllable thermal black bodies within the field of view
Spectrometer	four dichroic filters to split radiation in four optical ports, and diffraction gratings for each port
Detectors	Si array for VIS/NIR port; cooled InSb and MCT arrays for SWIR, MIR and TIR ports.
Spectral bands	continuous coverage in four spectral regions + single band at 1.5 micrometers

Figure 5 : a) Aviocar C-212-200; b) AHS spectral configuration; c) AHS main characteristics

3.1.2. The SIM-GA system

The Galileo Avionica SIM.GA HYPER is a 512 + 256-spectral-band push-broom sensor with VNIR and SWIR imaging capability.. The airborne hyperspectral system covers the 400-2450 nm spectral region and is operated for DIGISOIL campaigns on board of a the UNIFI ultra-light aircraft FOLDER at about 1000 m of altitude. The hyperspectral HYPER SIM.GA is composed of two optical heads:

1) VNIR Spectrometer with a spectral range of 400-1000 nm, 512 spectral bands with 1.2 nm spectral sampling, 1024 spatial pixels across a swath of 722 m (@ H= 1000m), which corresponds to a pixel resolution of 0.7 × 0.7 m

2) SWIR Spectrometer with a spectral range of 1000-2450 nm, 256 spectral bands with 5.8 nm spectral sampling, 320 spatial pixels across a swath of 425 m (@ H= 1000m), which corresponds to a pixel resolution of 1.33 × 1.33 m

The optical heads are managed by a common data acquisition and control electronics. The HYPER SIM.GA works as a push-broom imager where a spatial line is acquired at nadir and the image is made exploiting the aircraft movement. The optical head of HYPER SIM.GA is rigidly coupled to a GPS/INS unit that collects data about platform movements (roll, pitch, yaw, velocity, altitude, latitude and longitude) allowing the ortho-geo-rectification of acquired data. The use of GPS/INS unit reduces the mass and the cost of the instrument avoiding the use of a stabilized platform.

Given the aircraft velocity, it is possible to get the minimum altitude required to acquire the scene without under-sampling. The relationship is: H/v >25s, where: H is the aircraft altitude in meters and v is the velocity in m/s.

The actual instrument configuration allow to state that HYPER is best suited for studies/campaigns in which high spectral resolution and discrimination is a priority compared to the wide viewing for intensive mapping needs of whiskbroom systems.

SIM.GA technical specifications	VNIR	SWIR
spectral range	400-1000 nm	1000-2500 nm
spectral sampling	1.2 nm	6.3 nm
# spectral pixels	500	256
IFOV per pixel	0.7 mrad	1.3 mrad
digital resolution	12 bits	14 bits

Figure 6 : a) HYPER SIM.GA setup, b) the UNIFI FOLDER, c) Bottom view of optics through the sliding door, d) Main characteristics

3.2. SYNTHESIS OF RESULTS

3.2.1. Results on Luxemburg test area

SOC upscaling:

- Work flow

The hyperspectral data acquired from the AHS 160 airborne sensor produced the reflectance signal of the bare topsoil. This signal was then correlated with the C content of the plough layer (0-20 cm).

- <u>Calibration data and process</u>

We collected 19 samples of the topsoil (0-20 cm) in the selected Luxembourg test site (see D3.2 & D3.3, Figure XX). The C content was determined as outlined in D3.2.

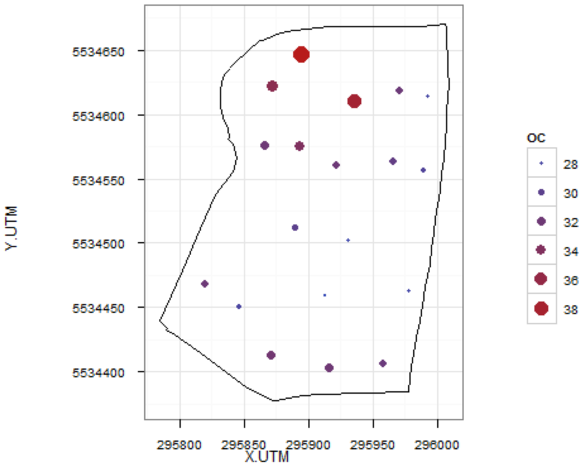


Figure 7 : Calibration points and their C content in the topsoil (0-20 cm)

Spectral data was analyzed with 2 different multivariate techniques: (i) Partial Least Square Regression (PLSR) and (ii) Penalized-spine Signal Regression (PSR). Statistical manipulations were carried out with the R software (R Development Core Team, 2010). We carried out the analyses for the visible and near infrared (VNIR : 400 -1100 nm) separately as well as for the VNIR combined with the shortwave infrared (SWIR : 1100-2500 nm). Further details on the methodology can be found in D1.3 and D3.2

- <u>C content maps at the field scale</u>

The spectral models produced the best results for the PSR technique applied to the spectra covering the VIR and SWIR (400-2500 nm). The spectra were calibrated and validated against the C content in the upper 20 cm of the soil. This corresponds to a homogenous C content in the plough layer. The PSR on the VNIR-SWIR proved to be the best combination of technique and spectral range. We obtained a RMSE of 3.43 g C kg^{-1} (Figure 8). The computation of RMSE is not entirely correct since it does not take into account the spatial autocorrelation of the errors. We computed an adjusted RMSE by block kriging of the squared errors and obtained a value of 3.63 g C kg^{-1}. This value is highly influenced by two outliers at the edge of the field and may be related to neighboring effects (Figure 8) The C content in the plough layer decreased from the northern border and the talweg to the southern part of the field (Figure 8).

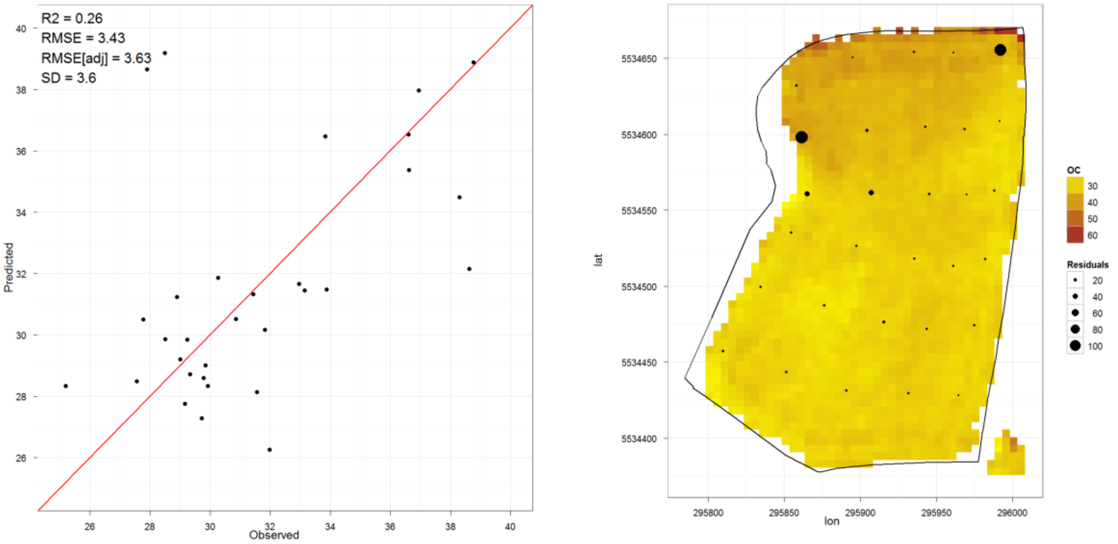


Figure 8 : (a) Predicted vs observed SOC content of the validation points; (b) Map of the predicted SOC content in the Luxembourg field, with the position of the validation points (dots) and squared errors indicated by the size of the points

- <u>C content maps at the regional scale</u>

Stevens et al. (2011) carried out an independent validation of the regional scale spectral models. The models are somewhat less accurate than the field scale model with an RMSE ranging from 4.5 to 5.4 g C kg^{-1}. In general separate models for each soil type or agricultural region performed better than global models. Multivariate calibration models trained under one condition may not yield good stability properties when applied under changing measuring conditions. At a regional scale , such situation is likely to occur during measurements in the field or using a remote sensing platforms as variations in the geometry of incoming solar radiations, surface characteristics (roughness, vegetation residues) and soil physical/chemical properties (soil organic carbon, moisture, clay, iron oxides, etc…) may result in important spectral variations. Stevens et al. (2011) showed that the accuracy of predictions at un-sampled sites depends highly on the location of the calibration samples in the multivariate space and their representativeness in relation to the entire spectral data cube. We recommend therefore carrying out a preliminary analysis of spectral variation in the image before the field campaign.

Exploitation

Soil organic matter (SOM) has many functions, the relative importance of which differs with soil type, climate, and land use. Commonly the most important function of OM in soil is as a reserve of the nitrogen and other nutrients required by plants, and ultimately by the human population. Other important functions include: the formation of stable aggregates and soil surface protection; maintenance of the vast array of biological functions, including the immobilization and release of nutrients; provision of ion exchange capacity; and storage of terrestrial carbon (C).

Soil organic matter has a central role in sustainable land management, but perspectives on the roles of SOM differ widely between farmers, consumers, scientists and policy-makers. Some consider SOM as a source of nutrients to be exploited, whereas others can afford to utilize it as a key component in the management of the chemical, biological, and physical fertility of soils. Still others see SOM as a dumping ground for excess nutrients and toxins, or as a convenient store for fossil fuel emissions, particularly CO_2. Farmers need sustainable land management systems that maintain OM and nutrient reserves.

In this field scientific knowledge and technology about the various roles of SOM and monitoring methods does not reach farmers and other decision-makers in a form that can be used easily. The biggest challenge for geophysical methods and remote sensing is to engage with clients to pinpoint gaps in knowledge and utilize new approach based on integrated geophysical/remote sensing information to devise decision support Systems tailored to their needs.

3.2.2. Results on Mugello test area

Clay upscaling:

Hyperspectral data from SIM-GA were used to retrieve a full processing procedure and finally to obtain a preliminary map of clay content relative to the Italian test site of Mugello.

Data collection

- A complete hyperspectral geocoded reflectance dataset was collected in September 2009 with an approximate pixel resolution of 0.6 m (VNIR) and 1.2 m (SWIR), at a flight height of about 900 m
- ground sampling in about 80 points (to a maximum depth of 5 cm; positions recorded with a differential GPS) contemporarily to the flight
- The quantitative determination of clay minerals content in 40 soil samples being performed by means of XRD and Rietveld refinement (Lutterotti et al., 1997; 2007).
- Indoor spectral signature collection from dried, crushed and sieved samples was performed using an ASD FieldSpec spectroradiometer.

Calibration and data processing

- Laboratory reflectance spectra for each sample where normalized with the “convex-hull quotients” technique (Van der Meer, 1995), thus eliminating the convex shape of the acquired signal allowing a direct comparison among absorption features where the depth of absorption peaks (i.e. clay minerals) can be considered proportional to the concentration of the atomic group, or substance, responsible for that absorption, presupposing that no other mineral has strong spectral features around that particular wavelength. Clay content and mineralogy influence the SWIR portion of the spectrum (1300-2500 nm)

(Ben-Dor, 2002), with peculiar absorption features at about 2206-2208 nm, due to the combination of OH and OH-Al bending (Chabrillat et al., 2002). Nevertheless, visual observation of collected ASD spectra allowed accurate localization of clay absorption peak at 2210 nm.

- A linear regression was used to relate clay content to the corresponding absorption peak depth values as shown in figure XX.

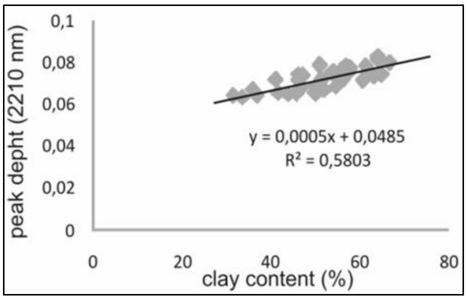


Figure 9. Relationship between measured clay content and absorbtion feature depth at 2210 nm

<u>Clay content map at field scale</u>

- The performed XRD mineralogical analysis showed that the amount of clay in the samples ranges from 30% to more than 65% and is 50% on the average. Montmorillonite and illite prevail, with minor amounts of kaolinite, as it is also confirmed by the occurrence of a single symmetrical absorption feature at 2210 nm, which is diagnostic for these minerals. On the whole, the shape of the ASD spectra is quite similar amongst the studied soil samples, except for variations in albedo and local differences in absorption depth values.
- Inversion of SIM-GA reflectance data into Clay content maps was performed on the basis of the linear fit between the absorption peak depth values at 2210 nm and the XRD total clay concentrations (R^2=0.6), as a consequence, our model can explain about 60% of actual clay content in the top level of soils in the study area. The result is showed in false colour in Figure 9, where red corresponds to higher values (higher abundances of clays) and black to lower (lower abundances of clays). Lower values are clustered in the northern part of the field, which is topographically more elevated, while an increasing trend can be observed towards the south (i.e.: parallel to the flow direction, towards the bottom).
- The validation was obtained through the comparison between the SIMGA derived Clay map and a clay map obtained from interpolation of laboratory XRD observed values, using the Inverse Distance Weighting algorithm: trends of measured and predicted values show a general consistency allowing to state that the 2210 nm peak seems to be diagnostic for clay minerals detection and mapping by means of hyperspectral remote sensing using the convex-hull approach.

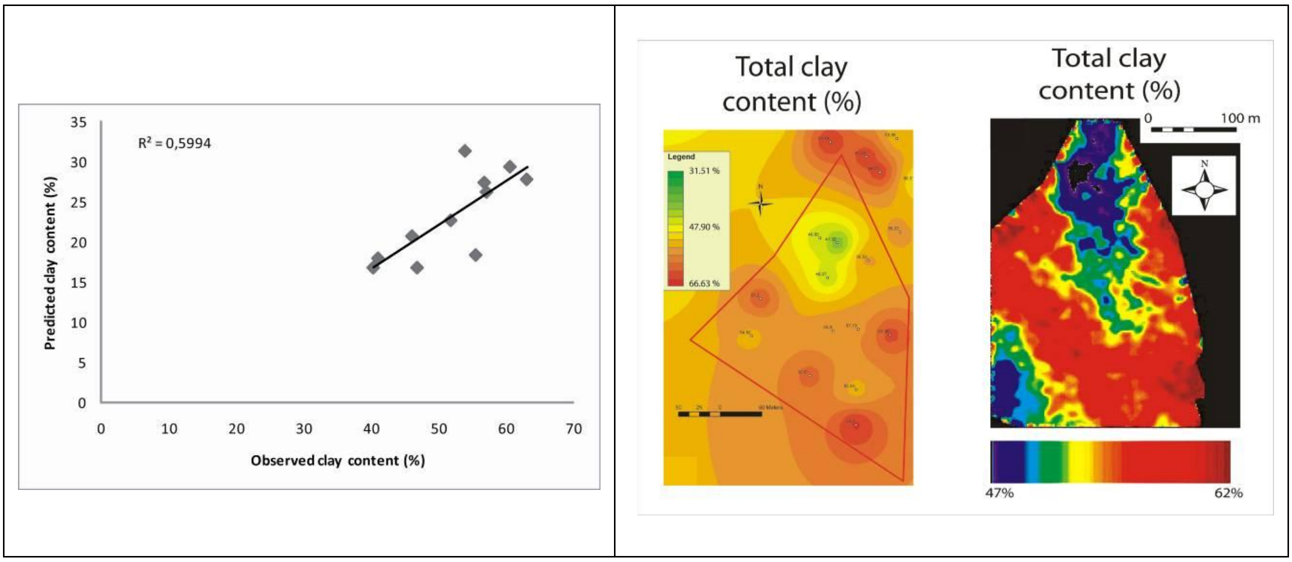


Figure 10. a) Linear regression between clay content predicted using SIM-GA and from the validation sampling data set ; b) Interpolated Total Clay map of laboratory observed values c) Total Clay map derived from airborne hyperspectral data.

<u>Clay content map at larger scales</u>

- Because of four different flight-lines of SIMGA Hyperspectral data were acquired, as well as other field measurements and laboratory analysis on soil samples were performed for extended validation over a wide area, the focus of regional scale validation test will consist of performing clay content map over the entire flight-lines for a covered area of about 5ha and make use of the additional available ground truth measurement for a more extensive validation and average accuracy estimation.

Standardization

A strong concerning about standardization of soil mapping methods depends on improvements reported in reports D4.2, D4.3:

- technologies
- processing algorithms
- inversion procedures
- manpower efforts
- integrated manpower skills
- operational management schemes

The estimated cost-impact of foreseen improvements is about 50% and 30-40% of reduction, but that one for integrated manpower skills and operational management schemes still remain to be evaluated.

An overall summary of needed skills and auxiliary equipment for a DIGISOIL-like soil mapping could be tried as follows:

		SISMIC	**GPR/EMI**	**GEOEL.**	**HYPER**
Skills	*Equipment calibration*	🟧	🟧	🟧	🟧
	Ground campaign management	🟧	🟧	🟧	
	Inversion algorithms	🟧	🟧	🟧	🟧
	Data/image processing	🟧	🟧	🟧	🟧
	Analysis results & validation	🟧	🟧	🟧	🟧
	Ground truth for cal/val	🟧	🟧	🟧	🟧
	GIS data outputting	🟧	🟧	🟧	🟧
	Airborne campaign management				🟧
	Ground/lab. spectral measurements				🟧
	Data fusion for 2°order maps	🟧	🟧	🟧	🟧
	GPS post-processing	🟧	🟧	🟧	🟧
Aux. Equipments	*Airborne*				🟦
	Quad	🟦	🟦	🟦	
	Panda penetrometer	🟦			
	Ground DGPS	🟦	🟦	🟦	
	Field spectroradiometer				🟦

Table 1. Skills summary needs for operational mapping

The quality of the relationships between soil properties and spectral features decreases significantly from laboratory-controlled measurements to SIM-GA data, thus demonstrating that the performance of this technique is strongly dependent on Signal-to Noise Ratio (e.g. signal level/quality and radiometric sensitivity of sensors) which address to illumination conditions, spectral refinement and polishing of data as well as atmospheric and radiometric correction algorithms.

With reference to clay mapping workflow was used in the framework of DIGISOIL Project (Figure 11) the standardization task should focus to the reduction of topsoil sampling and laboratory analysis were performed in the study phase up to the demonstration and performance estimation of the procedure. In the prototyping phase most of these efforts should be saved unless those necessary for final product validation and certification.

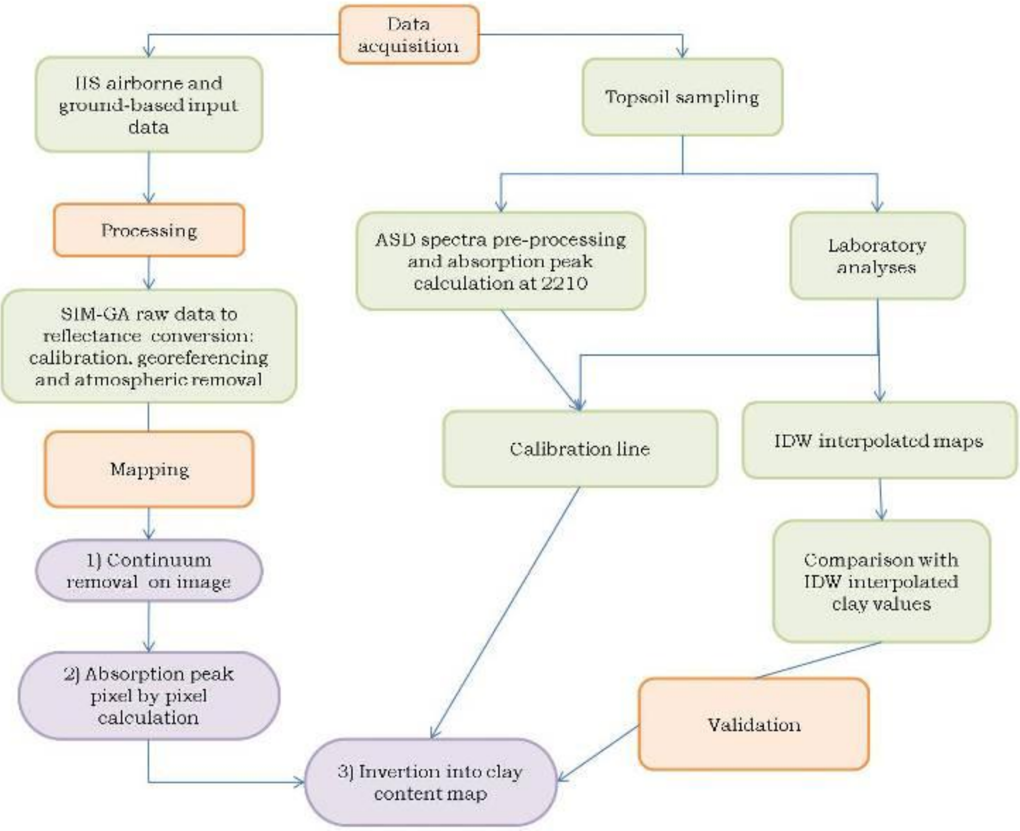


Figure 11. Overall workflow for clay mapping.

Exploitation

Over the past two decades, research on the use of visible–near infrared (VNIR) and shortwave infrared (SWIR) diffuse reflectance spectroscopy in soil science has increased rapidly and there are many reasons of interest. The main focus has been on basic soil composition, particularly on soil organic matter (SOM) and clay mineralogy, moreover, there are many reasons of interest for example the sample is not affected by the analysis in any way, no (hazardous) chemicals are required, measurement takes a few seconds, several soil properties can be estimated from a single scan, and the technique can be used both in the laboratory, in situ and from remote platforms (airborne, satellite).

Inferring soil properties (e.g. clay content) from Hyperspectral remote sensing platforms such as airborne and satellite (the latter will be operative within few years) makes digital mapping over large areas of such soil properties, allowing to save field and in situ activities up to a few needed for mapping validation and certification of the overall accuracy to the end-user. The remote digital mapping approach also include the great potential of the upscaling of ground geophysically based soil mapping at field scale, allowing a value added digital soil mapping through modelling of intrinsic relationships between soil parameters such as clay, water content, resistivity and bulk density.

These relationships and inversion modelling were one of the main focus have been investigated in the framework of the DIGISOIL Project and summarised in Figure…xxx.

The digital clay mapping exploitation also concerns with tailoring scientific added value DIGISOIL results (in this case clay content) to be assimilated in the end-user exploitation chain (agriculture, soil conservation, soil erosion management, etc.) considering delivery time, media, data format to make the operational steps easiest and quick as possible (e.g. web GIS, web Mapping, for database access and processing up to wireless mobile devices for prompt in-field decisions).

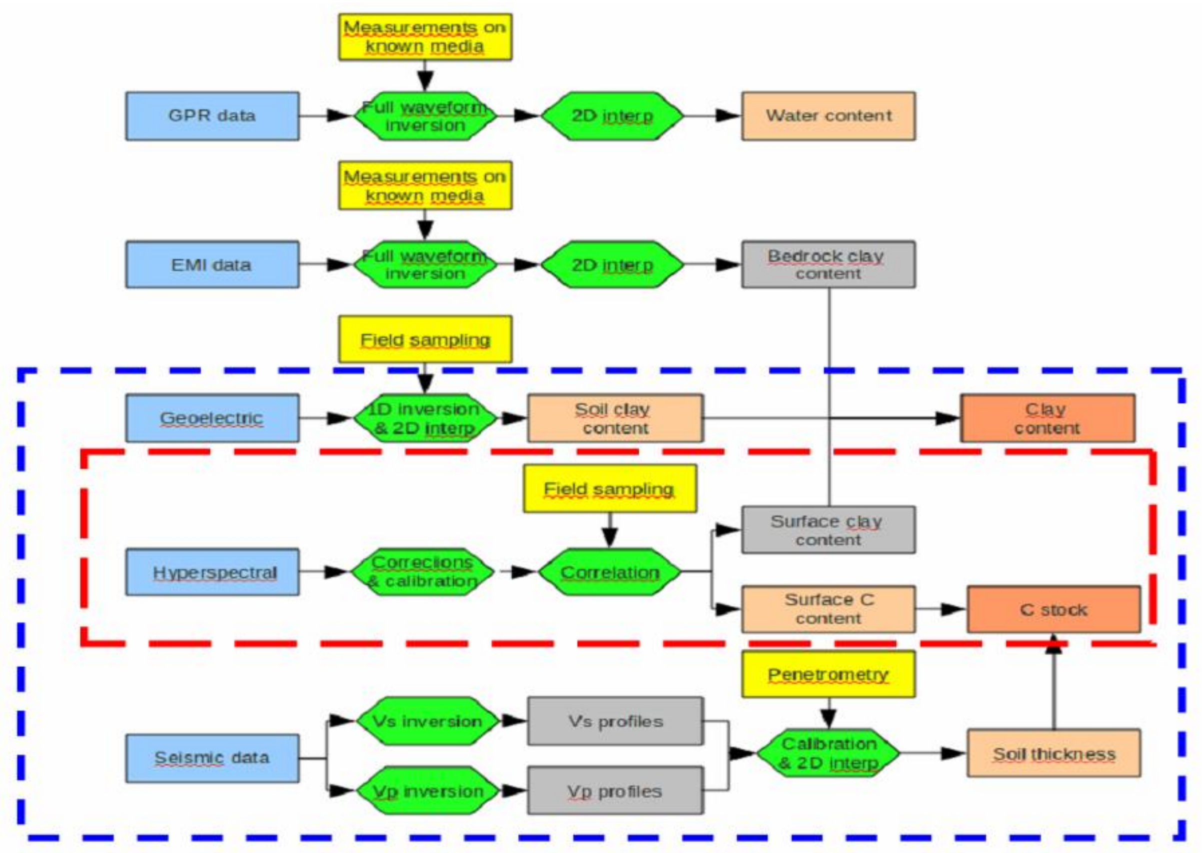


Figure 12. DIGISOIL workflow and synergies between hyperspectral and geophysical methods

3.3. ELEMENT OF COSTS

Mugello (IT) hyperspectral airborne campaign and cost analysis is based on the following main items/tasks:

1. equipment (ultra-light airborne the UNIFI Folder, an hyperspectral avionic system the GAV SIM-GA)
2. execution of the airborne flight-lines (UNIFI+GAV)
3. execution of ground measurement and soil sampling (UNIFI)

4. data preprocessing, calibration and compensations (GAV)
5. data analysis and results (UNIFI)

Averaged indicative ROM costs for a typical DIGISOIL mapping campaign based on hyperspectral operations as those carried out by partners UNIFI and GAV can be the following (see Report FPT7-DIGISOIL-D4.3 for details)

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

Figure 13. Summary of estimated cost for hyperspectral mapping

- Taking the same hypotheses than in the previous section for depreciation rates of equipment and software,
- 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.
- equipment/software used for airborne operations has been purchased, exceptions are the SIMGA sensor and the aircraft used 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 €.

For the hyperspectral the following calculation yields the relevant costs, based on the assumption of purchasing the SIMGA system and the aircraft instead of leasing them, the averaged prices for a typical airborne mapping campaign in Mugello can be estimated as follows:

[407840€ (physical equipment) / 10years / 20times + 18900€ (software+computers) / 5 years / 20 times + 32480€ (labour] / 128ha = **271€/ha.**

The following cost/efforts considerations can be done on this last result:

- Though the area covered by the flight operation is about 130 hectares, most of the costs incurred pertain to work carried out on the ground and for laboratory analyses in order to setup and validate the methodology on some well studied test fields of about 5ha. This means that this technique is potentially economically viable only when used for mapping large areas e.g. catchments but not field sized areas, as it is in principle, the aim of remote sensing techniques when observing from airborne and spaceborne platforms as well as when the calibration and validation methodology is well defined reducing in this way on-ground and laboratory efforts.
- When user needs are concerning mapping of only surface soil parameters achievable by Hyperspectral methods the average cost of 271€/ha is close to the

WTP indicated by end-users in D4.1 for low accuracy/resolution clay and carbon content maps.

Nevertheless, in order to be able to consider the some tasks can be optimized and efforts saved in order to be costs/ha more compliant with end-users WTP making them about 30-40% lower of the total amount after the followings improvements:

- The SIM-GA operator on ground can be restricted to 1 for worm-up, checking & download if the hyperspectral system is normally installed on the aircraft;
- For operational works, we could imagine that the inversion procedure from hyperspectral raw data to soil Clay/SOM properties is well consolidated and requires to perform reduced soil sampling and related analyses.
- The fore-optics of the airborne hyperspectral system could cover a wider field of view (FOV) allowing to save flight time for the same covered area.

4. Conclusions

This study aimed to deliver a summary of user manual of the DIGISOIL mapping tool. The operations needed to produce the different maps are presented, either for ground methods or airborne ones.

Considering the foreseen optimizations and efforts can be saved both for ground geophysics (about 50%) and airborne Hyperspectral (about 30-40%) operations as reported in sections 2.3 and 3.3 we can retrieve the maturity level for different maps/methods as estimated in the Report FP7-DIGISOIL-D4.3 (Figure 14). 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 maybe with further improvements to be studied or on the basis of business/commercial strategies.

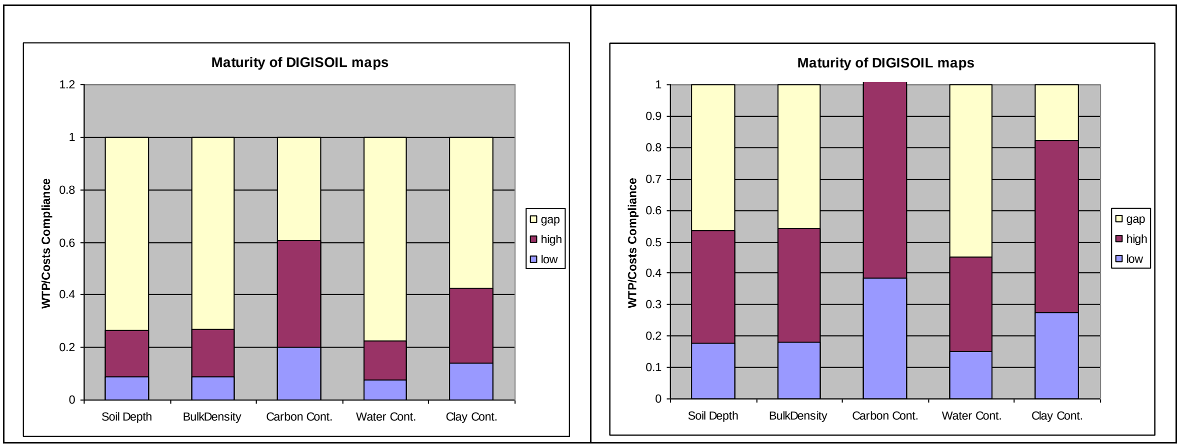


Figure 14. "Commercial maturity" of DIGISOIL maps before and after foreseen optimizationsThe technical solution of a single airborne Hyperspectral platform able to map C or clay content was studied. Compared to costs requested by ground techniques, this solution is better in the scope of end-users willingness to pay. On the other hand, such sensor can only retrieve surface properties with medium spatial resolution (2-5m) and low (±10%) to medium (±5%) accuracy. To evaluate subsurface information (properties featuring materials below the surface) and to reach an overall high accuracy measurements (< ±5%) ground techniques are essential.

In conclusions, the operational exploitation of the mapping tools realized in the DIGISOIL project reveals that both airborne and ground methods are necessary to operate. 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.

5. References

- I. Diafas, P. Panagos, 2011. Evaluation of the DIGISOIL mapping tool according to end-users' needs. Report N° FP7-DIGISOIL-D4.1; 21 pages.

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Scientific and Technical Centre
ARN Division
3, avenue Claude-Guillemin - BP 36009
45060 Orléans Cedex 2 – France – Tel.: +33 (0)2 38 64 34 34