Public document

Technical maturity of the DIGISOIL output relatively to user needs

FP7 – DIGISOIL Project Deliverable D4.2

N° FP7-DIGISOIL-D4.2
June 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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M. Thörnelöf (ABEM), M.Fontaine (BRGM)

Checked by:	**Approved by:**
Name: A.Vagner	Name: G.Grandjean
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Synopsis

This deliverable of the Digisoil project, D4.2, is looking at the usefulness of the concept and the approach of the project in relation to its receivers. All information has been extracted from the earlier phases of the Digisoil project. Added to that is information about related, already available technology.

With a focus on the end-user needs, the technical maturity of the output will be analyzed. The approach of the project as well as reported results is looked at. To assess the procedures as reported the technical readiness level 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.

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Abbreviations and Acronyms

BRDF	Bidirectional Reflectance Distribution Function
C	Carbon
CPS	Counts Per Second
DGPS	Differential Global Positioning
DSM	Digital Soil Mapping
EMI	Electromagnetic Induction
GPR	Ground Probing Radar
GPS-INS	Global Positioning System – Inertial Navigation System
HRS	Hyperspectral Remote Sensing
JRC	Joint Research Center
MUCEP	Multipole Continuous Electrical Profiling
NASA	National Aeronautic and Space Administration
OM	Organic Matter
PTF	Pedo-Transfert Function
SIM.GA	Sistema Iperspecttrale Multisensoriale – Galileo Avionica
SME	Small and Medum Enterprises

SOC	Soil Organic Content
TDR	Time Domain Reflectometry
TRL	Technology Rediness Level
VNA	Vector Network Analysers
WP	Work Package
UML	Unified Modeling Language
UMR-LISAH	Unité Mixte de Recherche - Laboratoire d'étude des Interactions Sol - Agrosystème – Hydrosystème

1. Introduction

In Work Package number 1, Deliverable 1.1 the following is stated:

"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 experience will allow taking **into account the feasibility of such developments based on economic constraints, reliability of the results and needs of the DSM community**."

This report will assess and evaluate the product envisaged by DIGISOIL. To reach the result the field trials as well as the data processing and the presentation of the final results have been looked at. Further to that, a benchmarking approach against already commercially available solutions has been made.

Looking at the large areas exposed to the threat of soil degradation, either by misuse or over-exploitation, it is obvious that the need to collect information is a tremendous challenge. There is a variety of options available to ensure that good and reliable information is collected. The first obvious choice may be to collect soil samples for analysis. However, if the time and labor requested for the collection and analyses of the samples is introduced as a parameter in the equation it is easy to realize that collecting soil samples is not the solution at hand, instead other options must be identified. The core objective of DIGISOIL, mentioned above, is to find a time and cost efficient solution based on geophysics that will, in an orchestrated manner, together with both a priori information and new information from soil samples that can be used for calibration and correlation contribute to a sustainable utilization of the soil.

1.1. GEOPHYSICS A TOOL FOR SOIL INFORMATION

The DIGISOIL project has shown that geophysics is a viable addition to the tool box of the soil scientist. However, it has also shown that it is of vital importance to continue the research and development of both the hardware concept and the processing of the outputs to fully reach the needs of the end users. An attempt has been made in the conclusion of this report to suggest what needs to be done before a working solution is in place for the end user category.

It is clear that the geophysical methods chosen in the Digisoil project can provide information about the targeted parameters. However, a greater understanding of the interrelated processes that leads to the specific geophysical record for a given method is required. Geophysics is however, a very powerful tool of information that adds to the knowledge about the prevailing soil conditions.

Another function of high interest which geophysics meets is the capability to cover large areas within a reasonable cost frame. If this functionality is coupled to the point source information, which for example a soil sample is an example of, it opens a highway to large scale mapping of soil properties that is both calibrated and correlated. This in turn is an information source for the future decisions. There is a high potential for the society to gain substantially with the additional information acquired.

1.2. PARAMETERS & METHODS

The parameters to focus on have been set in the earlier phases of the Digisoil project, in concordance and collaboration with the soil scientific community. In figure 1 below is outlined the work flow from the initial stages of measurement to the potential contributive input with in the DSM sector. Focusing on the three main parameters, clay content, water content and carbon content, which play a major role in controlling the soil properties for the utilization of the land, Digisoil has the intention to outline an improved and integrated approach to digital soil mapping. Test measurements have been made and wherever an already established method is employed at least partial costing. When more innovative methods have been tried more emphasis has been put on creating a working system. The cost effectiveness estimates is in these cases only seen as indicative information. More experience from field trials as well as data processing is required before a detailed analysis is made.

Further to the field campaigns for collecting data, a large portion of the consumed man power resource have been used for the processing and follow on compilation of map material. It is clear from the earlier reported work of Digisoil that the processing of data and compilation of soil property maps must be given ample time in the assessment of the readiness of the methods for DSM purposes. The finding of such an exercise may as well result in recommendations that indicate that the geophysical tool itself is not the final and foremost product to be delivered. The readiness of the agronomic community is high for new technology – as long as it does not decrease their productivity. A web survey made by JRC and targeting the interest in new technology and/or services gives an indication of the interest, see figure 1 below.

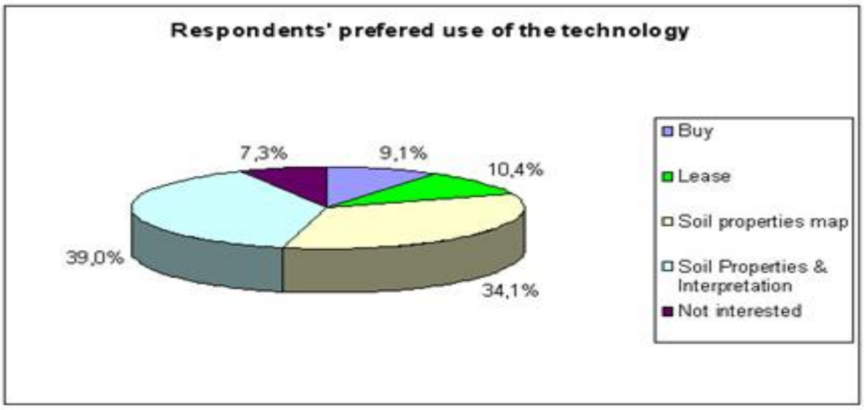

Figure 1 : Potential users' response (from JRC webpage about the DIGISOIL project[1])

However, even if the computer literacy is high the indication from a web survey made by jrc for soil parameter tools and / or information is heavily inclined towards the results and not the tools.

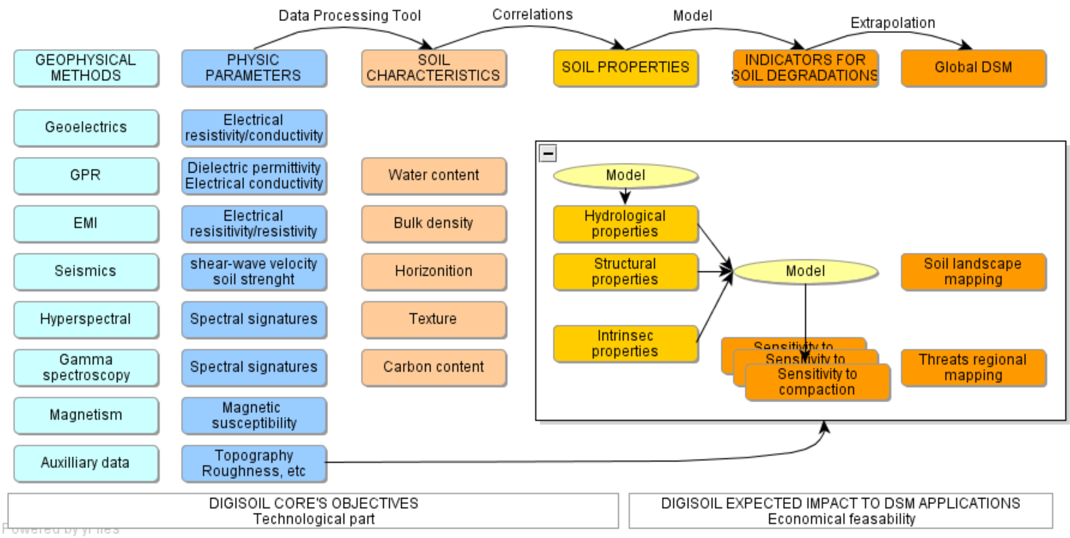

Figure 2 :Concept work flow of the DIGISOIL project (from D1.1 p. 12)

[1] http://eusoils.jrc.ec.europa.eu/projects/Digisoil/Survey.html

1.2.1. Methods

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 measuring 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 platform.

Geophysical methods	**Physical parameters**	**Relevant Soil Parameter**
Ground-penetrating radar (GPR):	Dielectric permittivity, electric conductivity, magnetic permeability, frequency dependence of these electromagnetic properties	Clay content,
Seismic reflection and refraction:	Volume and shear-wave velocities	Depth to bedrock, overburden composition
Electromagnetic induction (EMI):	Electrical resistivity (electric conductivity and frequency dependence)	Water and clay content
Electrical resistivity (geoelectric):	Electrical resistivity (almost zero-frequency)	Water and clay content
Magnetics:	Magnetic susceptibility and viscosity	Ferric content and stability
Airborne hyperspectral:	Spectral reflectance	Organic (C) content

Table 1: Geophysical methods suggested, physical and soil parameters

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1.3. TECHNOLOGICAL LEVEL REQUIRED / CONFIGURATIONS

To reach the intended levels of information it is important to secure a good data quality. It should be noted that the geophysical methods in DIGISOIL has not been adopted for use by the tentative end users themselves at this point. It is required that the operator has acquired an adequate level of knowledge and skills to secure that good quality data is collected for the DIGISOIL project. Thus it can well be said that the maturity, from the end user perspective is low. Further development is required before a higher level of maturity is reached.

Further to the above there are factors as repeatability and reliability. These two functions may interfere with the possibilities to use data in on a wider scale if they are not handled in a correct way. It has for example been shown for the EMI method that it is detrimental to the consistency of the data if not the calibration is handled with outmost care.

Metrological vectors may also influence the reliability and repeatability of measurements and should thus be considered as well. For example a period of precipitation may affect the water content levels considerably.

In its extension it must be looked at how this is applicable to the end users of the result. Foreseen are then at least two categories of end users of the results:

- Decision makers within the regulatory framework for the exploitation of the land.

- The users of the land themselves for optimal sustainable utilization of the land.

Both user categories can with the additional information made available thanks to the geophysical measurements avoid making mistakes as well as getting the best out of a defined area of land. For example, a farmer should not use fertilizers if the soil cannot hold it or a decision maker may change the use of the land due to high degree of degradation and vice versa.

1.3.1. Definitions

In the field work of DIGISOIL has been used several different methods, in order to streamline and make the concept as efficient as possible the project have looked at the possible configurations. The methods used in the DIGISOIL can be subdivided in three groups when it comes to how the respective method is applied. In the DIGISOIL project the measurement methods falls out in the following groups:

Airborne: The method is not depending on direct contact or closeness to the target of the measurement. Method used in the DIGISOIL project in this group is the Hyperspectral measurements

The ground based methods split up in two groups:

1. Closeness to the ground is required but no direct contact with the ground is necessary. Methods used in the DIGISOIL project in this group are Ground Probing Radar (GPR), Electromagnetic Induction (EMI) and Magnetics.

2. Direct contact with the ground is required. Methods used in the DIGISOIL project in this group are Seismic and Geo-electrical methods as Resistivity and Induced Polarization.

To form an efficient investigative solution it is of interest to be able to measure both from a distance and while moving. Both this functions will increase the area of investigation covered for a given time frame. Even if both mobility and areal cover is vital functions for the success it will also be required to establish a framework of true in-vitro samples that can be used for correlation and calibration.

While the static methods as seismics and non-mobile geo-electrics may still be required in the initial steps of research to a certain level in the effort to build an extensive database for soil characteristics it is of interest for the continuation to focus on mobile configurations, especially with the productivity of results as a focus.

Productivity is not only dependent on the factors mentioned above. To reach a useful product that the tentative end users will utilize there is a considerable amount of processing to be made. The time and effort for the processing must also be brought into the total calculation when the cost effectiveness is estimated.

1.4. SITES, METHODS AND RESULTS

In the DIGISOIL project a number of representative sites were chosen for the field trials. These sites represent different soil conditions for Europe, in respect of geology, meteorology and land usage. The core task of DIGISOIL is to device geophysical methodologies for soil characterization. At the chosen sites the geophysical methods have been tried and the results have been analyzed. Hereby, a focus has been laid on the methods success rate for its intended purpose. All sites have been looked at and the result is reported below.

1.5. PROCESSING OF RESULTS

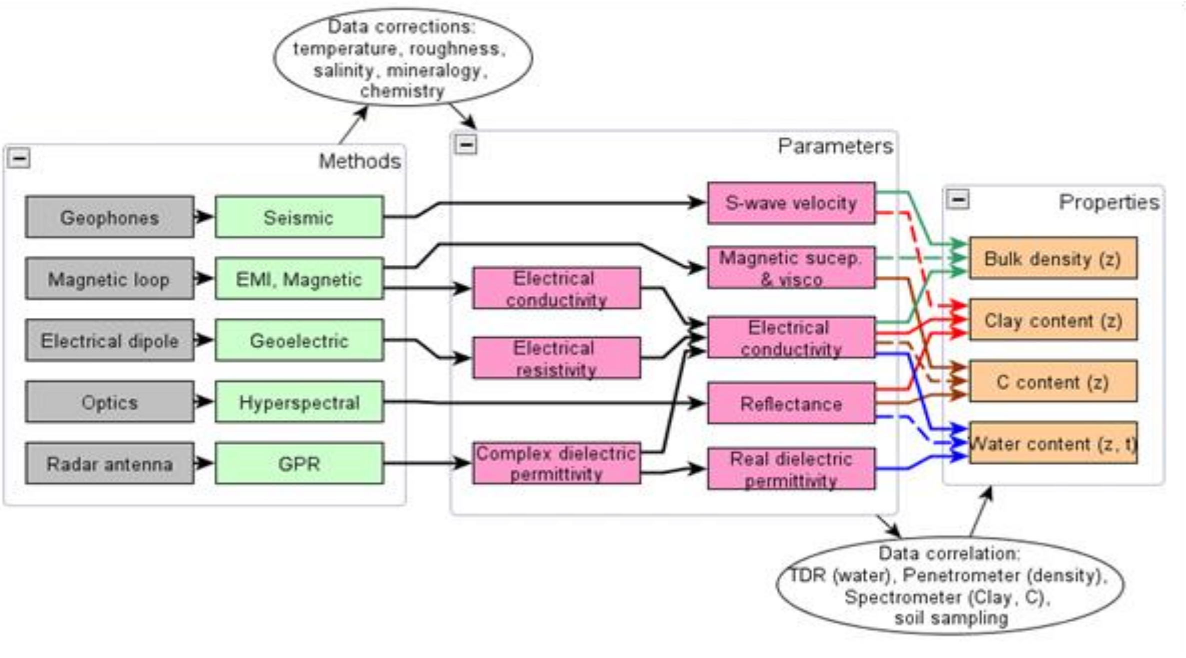

Figure 3 : Concept diagram showing the different paths for going from sensors to soil properties(from D2.1).

1.5.1. Data collected and result after processing

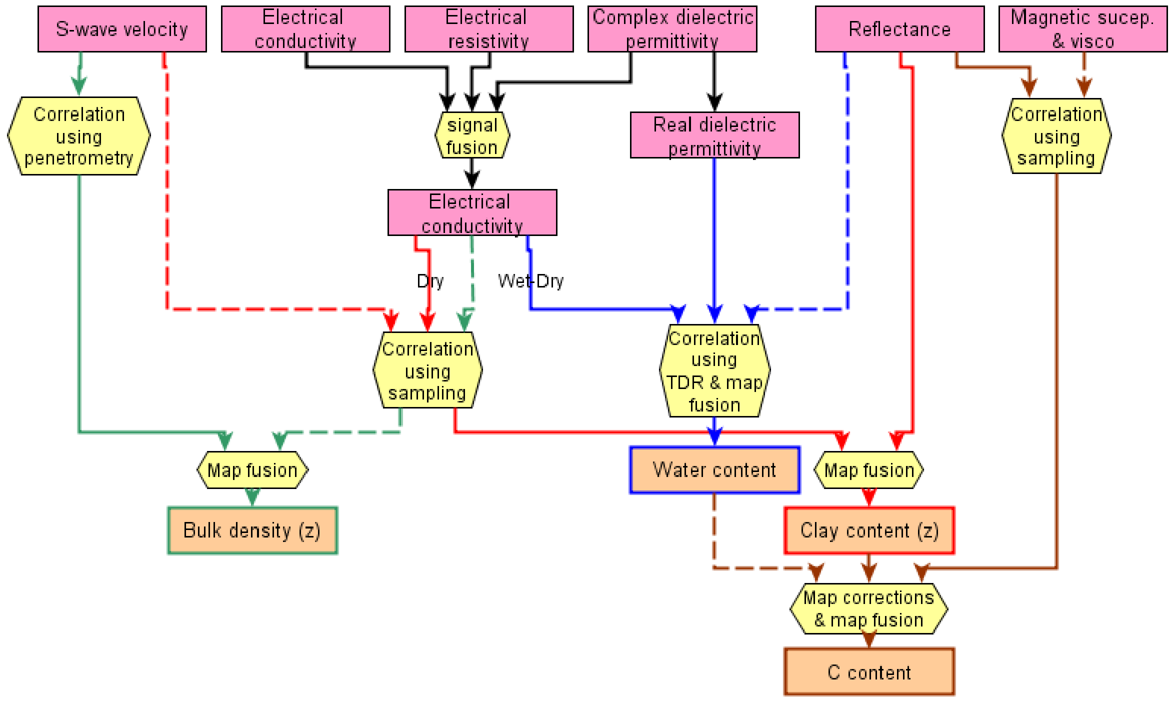

Figure 4 : Data assimilation from geophysical parameters to soil properties (from D2.1).

According to Figure 4, the estimation of the soil characteristics targeted in the Digisoil project can be based on the four processes as described below:

1.5.2. Density

The density parameter is established using seismics, geo-mechanicals and soil sampling. Analyses of the inputs are made for identification of density profiles and further correlation with geo-electric data. Input data from dry conditions, geo-electrical, GPR and seismic, is processed for identification of density profiles and layering structures. Finally the combined results are merged into a map based on the processed results.

1.5.3. Water content

An Important parameter, both for the geophysical measurements and the utilization of the soil is the water content. To establish a clear picture of the distribution of the water saturation the hyperspectral reflectance data has been processed for finding the highly saturated soils at the surface. Soil moisture at the surface and vertical water saturation profiles have been identified by processing of GPR/EMI data. Geo-electric data collected in wet conditions has been processed for identification of water saturated layers in the soils. In situ Time Domain Reflectometer (TDR) measurements have been made for the calibration of the different source maps. As a final step the reflectance information and the soil moisture saturation information from the GPR/EMI and geo-electrical measurements are merged into a compiled soil moisture distribution map.

1.5.4. Clay content

One of the most important components of the soil composition for a soil formations water bearing / holding capacity is the clay. Thus the project is aiming at establishing information about the clay content. To increase the information database the clay content has been established using processed hyperspectral reflectance for the clayed surface. Geo-electrical/EMI and seismic inputs from dry conditions have been processed for identification of clayed layers in the soils. To ensure good correlation between the geophysical measurements and calibration parameters soil samples have been analysed for the identification of the clayed layers. Finally, the compiled information has been merged into a map for the clay content distribution.

1.5.5. C content

The amount of organic matter (OM) in the soil is of importance for the utilization of the soil for especially farming purposes. A good indicator of OM is the Carbon (C) content. Thus the C content has been established through processing of hyperspectral reflectance and magnetic susceptibility data for the C content. Soil sampling and soil analyses has been made for identification of clayed layers and correlation. Maps of the C content have been compiled through correlation between soil sampling, reflectance and magnetic susceptibility. As a final step the C content maps has been corrected using the clay and water content maps.

1.6. TECHNICAL ADVANCEMENTS OF THE PROJECT

The level of Technical advancement is high in the project. An adaption of already known methods originally developed for mineral exploration as well as fusion with the latest technology advancements to be found. New approaches for data treatment and how it can be linked with a-priori information has been looked into. Further to that also co-interpretation us

There exists a palette of geophysical methods that is available for applications within the soil science sector. The methods used in DIGISOIL have a longer or shorter record for this application. The novelty factor is probably largest when it comes to combining the results of the various methods into a comprehensive picture for the near surface soil sciences.

Farthest regarding the use of geophysics as a tool for better understanding and utilization of the land has the large scale farmers reached. It is also in this niche where it can be found some information to benchmark against. Further to that information can also be extracted from other projects within the Soil Science sector.

The reported results in the Digisoil project are basically from the experimental stage of the field measurements. Thus maybe the full potential of some of the chosen methods for the application has yet to be established.

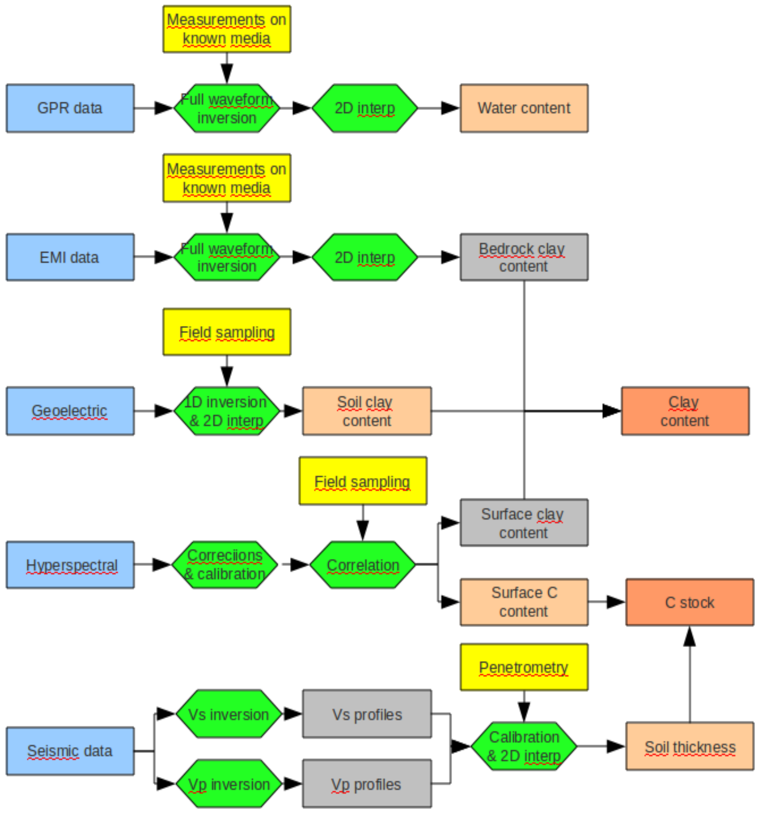

Figure 5 : Revised workflow of the Digisoil's system for estimating soil properties maps(from D3.3)

2. Assessment of the Digisoil concept using the Technical Readiness Level method

2.1. THE TRL METHOD

A step or scale configured assessment method called the “Technology Readiness Level method” (TRL) was devised within the space program of the USA in the 1980’ties as a tool for the management for decision-making. It has later been adapted to several fields of complex research and development projects. The original TRL schedule consists of nine levels (see Fig. 6 below). However, in this report the original levels have been adapted into three main levels applicable for a project of Digisoil’s character. The adapted highest level does not reach level 9 of the original TRL.

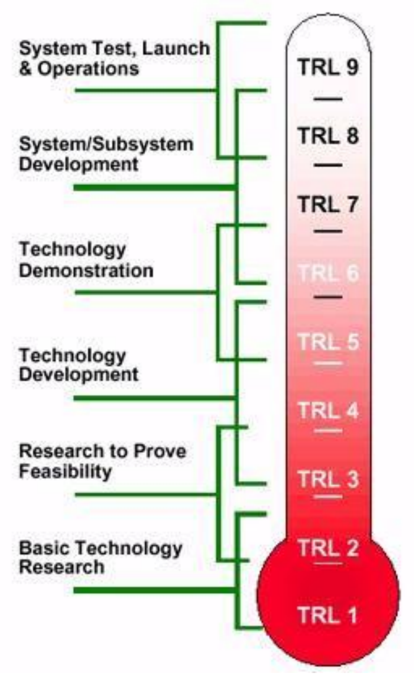

Figure 6 : *TRL levels as described by NASA (from Wikipedia[2])*

[2] http://en.wikipedia.org/wiki/Technology_readiness_level

The three levels mentioned can also be expressed as research, technology study and applied technology and/or validation. For the assessment of the maturity of the concepts envisaged in Digisoil the previously compiled material has been used as a base. In the following text an outline structured as per the TRL method is presented

2.1.1. Research and Technology – TRL Digisoil adapted level 1

The basic assessment level corresponds to TRL levels one, two, and often three (Fig. 7 below, yellow arrow). Translated into the Digisoil project this corresponds to the results reported in WP1 and WP 2

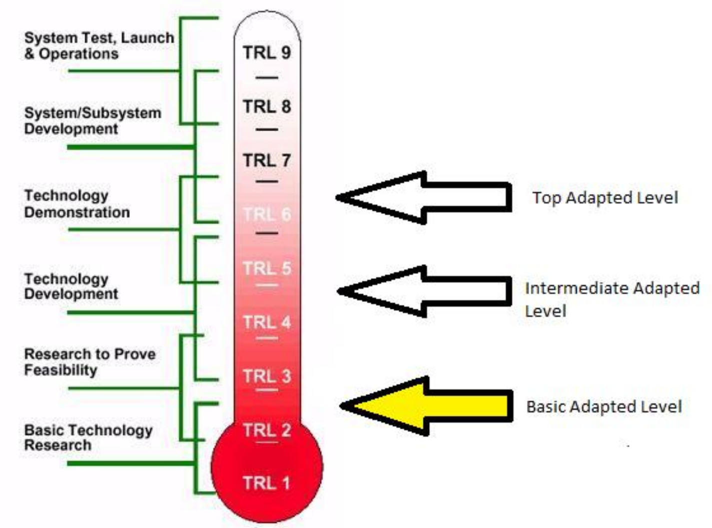

Figure 7 : *The basic assessment level corresponds to TRL levels one, two, and often three.*

The question raised is if there are geophysical methods available that can provide information about the chosen parameters in the project. The most relevant soil parameters to be identified and mapped as indicators for the soil degradation are bulk density, clay content (texture), water content, Carbon content and sub-surface layer topography.

The approach has been to identify suitable geophysical methods for the purpose. A focus has been given to methods that have a potential to cover large areas with less resource input. A wide range of methods have been looked at both airborne and ground based. Mobile or “quasi”-mobile solutions are for the same reason to be preferred as productivity is a key function for a successful result.

The choice of geophysical methods is a mix of existing technologies and new technologies for the application of soil parameter measurements. For both types of technology the need of development and adaption to the soil science is of varying degree. In some cases it is just a question of smaller adjustments of the hardware while in other cases the software is the hampering factor. To some degree there is no experience available to be tapped. Further to the mentioned issues the project has also looked at the potential of combining the different geophysical methods. It is envisaged that combining methods, both from a practical point of view for effectiveness in the field situation and from a result point of view for the content in the final product, that is to be presented to the potential end users, is required. The compound effect is expected to save both time and money as well as improve the quality of the output product.

The first Work Package of Digisoil, WP 1, involves studying the various geophysical techniques with an aim to select a range of geophysical technology that would meet the criteria of the project, a potential geophysical multi-technique tool for improved soil characterization adding to the digital soil mapping information database.

Geophysical methods	**Physical parameters**	**Relevant Soil Parameter**
Ground-penetrating radar (GPR):	Dielectric permittivity, electric conductivity, magnetic permeability, frequency dependence of these electromagnetic properties	Clay content,
Seismic reflection and refraction:	Volume and shear-wave velocities	Depth to bedrock, overburden composition
Electromagnetic induction (EMI):	Electrical resistivity (electric conductivity and frequency dependence)	Water and clay content
Electrical resistivity (geoelectric):	Electrical resistivity (almost zero-frequency)	Water and clay content
Magnetics:	Magnetic susceptibility and viscosity	Ferric content and stability
Airborne hyperspectral:	Spectral reflectance	Organic (C) content

Table 2: Main ground-based and airborne geophysical methods, related physical parameters and relevant soil parameters (Adapted from WP1/D1.1).

Criteria when selecting technologies have involved the aforementioned properties. Further to that, technologies have also been carefully chosen to measure the same key soil parameters using different technologies. The use of different methods for the same target will further the quality of the data processing.

It is very valuable for the processing of the gathered information to have access to several methods. The additional information available has been used to both correlate and constrict the processing of information in such way that the processed result is further enhanced in quality and detail.

For calibration purposes of the geophysical input to the digital soil maps well established techniques as penetrometer tests and collection of soil samples are suggested and also used. A note is made about metrological conditions during measurements as being of importance if results from geographically well separated areas are to be made comparable. Expected is that even if there are smaller regional variations of the conditions it will be a very difficult task to do global comparisons. Metrological factors are also important if comparisons over time are to be made.

2.1.2. Technological studies – TRL Digisoil adapted level 2

The intermediate assessment level is identified as TRL levels four and five (figure 8 below, yellow arrow). Within the Digisoil consortium the group has a high degree of competence in the geophysical techniques that are used. The close relations to the academic sector ensures that the research within the technology holds a high standard as well as being on the edge of what is possible to accomplish with the available tools. This environment also gives a lot of possibilities for the adaption of chosen technologies for optimum results. Further to that, the results of the measurements are carefully prepared, processed and evaluated.

In Work Package 2 of the Digisoil project, the task is to concretize the path forward for the field campaigns to be made under Work Package 3. It also includes the outlining of the treatment of the acquired information.

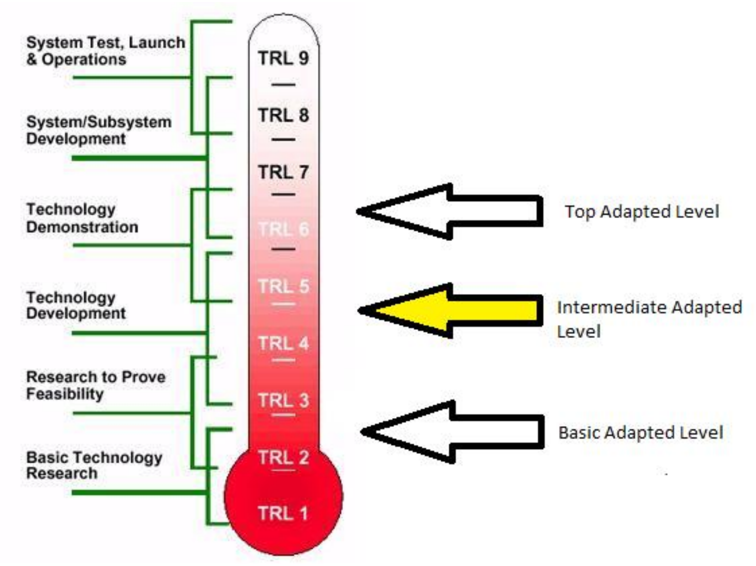

Figure 8 : *The intermediate assessment level is identified as TRL levels four and five.*

A thorough study of the soil characteristic influence or interference in relation to the suggested geophysical techniques has established the relation between the geophysical measurements and the soil characteristics. In the work of defining the relationships a pedotransfert function (PTF) approach was used. This type of approach has been used for more than 100 years within the soil science sector. The PTF method is defined as predictive functions of certain (soil) properties from other more available and easily measured properties. In the case of Digisoil the PTF has been suggested as the vehicle for the transformation of the geophysical data collected into soil characteristics.

Further to the immediate use of the PTF, it is a useful approach as it is a widely accepted approach for quantifying information in different units than its origin. Further to that PTF also encourages joint inversion of the results which in turns secures that the parameter is as correctly reported as possible. Finally, it will add to the credibility of the results in the eyes of the end users as a large percentage is soil scientists.

This level also involved testing and calibration of the technics selected. The history of geophysics has shown that empirical knowledge is not to be underestimated in the process of understanding the results and the coupling to the target of the survey. In WP 2 of Digisoil a detailed and solid study is presented. It details the findings from empirical experiments, both in the field and in the laboratory. Assessment has been made of the selected techniques to find the envelope for the method in the application at hand. The experimental phase also included investigation of the influence of the seasonal variation. The measurement conditions can vary considerably depending on the amount of precipitation, which can give a large variation of the water content in the upper soil layers initially. In addition to the aforementioned also the farming sequence over the year changes the measurement conditions widely with the farming areas going form bare soil to fields carrying fully grown crops.

The reported results indicate that the choice of techniques and approach to the practical field work is well within the scope of the target of the project – a mapping tool for digital soil mapping. There are differences in the status of the readiness of the techniques, with EMI, GPR and magnetometry taking a lead followed by seismics and resistivity with the hyperspectral bringing up the rear.

EMI and GPR are both methods that are highly mobile and can measure while in motion, which was partly applied in the project. Thus these techniques do already have concepts for mobile measurements. This makes the adaption into a combined geophysical tool for soil parameter measurements a relatively straight forward task. The mobility is a positive quality especially in the case of covering areas of catchment size. The magnetic measurement for validation was made as static point measurements as they were aimed at measuring susceptibility and viscosity of the magnetic material in the soil.

The other two groundbased geophysical methods, seismic and resistivity, does not have the same mobility. New practices have been introduced in order to speed up the measuring sequence. For the seismic method a type of self-righting gimbal sensors shows promising progress in this direction. If this is combined into a land streamer with fixed spacing the method can eventually reach a semi-moving measurement sequence. Still the sensors need to be completely static during the actual recording at a given station.

For the geo-electrical method it has until recently been a static method for the onshore based measurements. However, during the last two decades it has been further developed into mobile systems that can measure while moving. The main problem in applying the geo-electric method as a moving system is that the contact points need to have galvanic contact with the ground. Promising pilot measurements are made at several places around the world. With a mobile geo-electric system the solution of the contact problem is either in the shape of a harrow or a streamer. In the case of the harrow like configuration contact is represented by the discs. While for the streamer each contact point needs to have some weight to ensure that good contact is secured.

The hyperspectral method is the only airborne method used in the Digisoil project. Being airborne the method has the largest potential for areal coverage of the methods selected. It is the newest of the methods thus there is more research to be done before it is perfected. The hyperspectral method focuses in the uppermost part of the soil and as it measures over a spectra it contain information about several of the parameters of interest. For the application within the Digisoil project tests were made for the use of reflectance information with a focus for mapping of the soil organic content (SOC) at the surface.

As with the other selected methods both laboratory tests for calibration of the specific technique and field trials were made. For the hyperspectral method it is of vital importance that the measurements are measured when the soil is a bare as possible. Other factors that affect the immediate results are if the soil is harrowed or only tilled. Another factor is again metrology as hyperspectral reflectance measurements is not only affected by precipitation but also the sun.

This phase of the project has focused on identifying the methodology for the acquisition of the geophysical data and has made a thorough investigation presented in WP 2 which will be the platform for the next step. It outlines both the strong poins and the weakness points for each geophysical technology. As a good example can be mentioned the geo-electrical measurements where it is shown that response depending on the water content affects the measurement to such a degree that it in this particular case overshadows the response from variation in density.

Clear from the results of the experimental stage of the project is also that there is a large portion of data treatment to account for before the information from the geophysical methods does contribute to the DSM information. Not only it is a question of first order inversion of data but it is also finding the right lattice for the first order maps to be combined into second order maps and the compound maps to follow as the final product.

2.1.3. Technological demonstrators – TRL Digisoil adapted level 3

The top assessment level of the Digisoil project is equal to TRL levels six and seven (figure 9 below, yellow arrow). On these TRL levels the project it is in the phase of validating the findings from the earlier research and experimental work done in Digisoil.

The successive work would be to put the concept in productive work. However, in the Digisoil project the final action is the validation of the concept. To verify that the assumptions made would meet the criteria set up at the beginning. Along the work to achieve secure knowledge about the relation between the geophysical measurements and the soil parameter point information for the test sites were assembled.

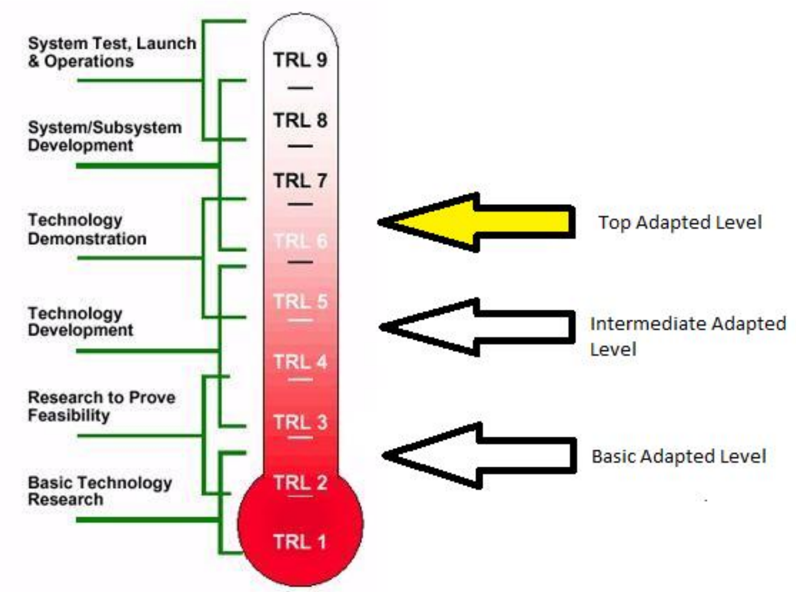

Figure 9: *The top assessment level of the Digisoil project is equal to TRL levels six and seven*

Test sites representing different soil types that are both exposed to extensive farming and heavy use and threatened to soil degradation has been selected, one in Luxembourg, one in Italy and one in Hungary. These three sites represent three different types of soil conditions and compositions as well as different types of utilization. Furthermore the sites are documented through earlier investigations and only complementary investigations coupled the geophysics were necessary. Accessibility is another parameter when surveying on land where farming is active.

In WP 3 the focus is an experimental approach to apply the methods at new sites in order to validate the earlier experiments done in the laboratory and under comparably controlled circumstances. The geophysical work is presented in D3.2 and contains a systematic presentation of the results of the work. The only aspect that shows larger variation in the presentation is the technical or economic constraints. For the assessment of the methods with a commercial approach it would help a lot if these parameters where reported using the same references. Now it is moving between unmentioned area size (only to be found at a different place in the report), specified area per day to velocity of measuring vehicle or time needed for a site. It is well understood that there is a difference between the practical field work done and the further work employed to treat the collected information.

At the onset of the project it was initially considered that all envisaged and selected geophysical methods (see table 2 above) should be employed for the selected test sites. However, at the end it resulted in a sequence of measurements where the different soil types were measured by geophysics (see table 3 below). The measurements were made under specific timespans, even if they did not coincide so all measurements could be made during the same time span. For example the hyperspectral measurements require a bare soil which in a farming field is not always accessible for ground based activities, depending on the crops planned. However, all these factors have been handled with care.

Localization Site coordinator	Soil properties to be investigated	Techniques applied on the sites	Site characteristics	Associated Soil types (WRB)	Obtained results
Luxembourg-LU UCL	C content Density/Stifness 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 UNIFI	C content Soil depth Clay content	Hyperspectral Seismic GPR/EM Geoelectric	Mediterranean area Traditional agriculture Soil database availlable (OM, erosion model)	Calcaric REGOSOL	C content map Soil depth map Water content map Clay content map
Zala-HU UPA	Water content	Geoelectric	Western Hungary: continental area Intensive & traditional agriculture	Haplic CAMBISOL, Haplic LUVISOL (majority), arenic LUVISOL, FLUVISOL	Water variability on time

Table 3 : Test sites and their characteristics and techniques applied in Digisoil (from D3.2)

The results are elaborated and calibrated and corrected as per the, in the earlier phase, described procedures. However, the actual processing of data is not detailed in this phase as it was dealt with in the earlier phase. Instead the recorded results are presented together with the validation procedure. Both the first order maps, the direct inversion of the geophysical data and the second order maps generated from a combined set of first order maps contains a lot of useful information for improved knowledge about the soil parameters on a larger scale.

It is however clear from the reported procedures and efforts that even if the geophysical tool suggested by Digisoil is on the right track there is need for more development and research before it will be a ready as a product to be presented to the potential market. However, the results as processed does already have potential to be attractive for the end users.

3. Conclusions

3.1. MATURITY

The geophysical concept brought forward in the Digisoil project shows much potential in being a useful contribution to the digital soil mapping efforts. The added dimension of geophysics will allow that a lot of point based soil information from for example soil samples can be extrapolated into more continuous information flow for the generation of soil property maps. This will enhance the knowledgebase for the end users of the product.

The intention of the field campaign for the respective site is that it should be time coordinated to take place in a fairly short time span to minimize a varying influence of variables as weather and farming preparation work of the land, i.e. tilling, harrowing or collecting crops. The benefit of concentrating the measurements in a given timespan is that the results can to a higher degree be cross-correlated and one technique may strengthen the quality of the output for another technique. The other benefit of a time limited effort for the measurement is that it will not be an obstacle for the regular use of the land as farming and thus encouraging the land owners/users to permit access to the area.

3.1.1. Methods, reproducibility and availability

The choice of methods or techniques is good but to some extent it is most probably biased towards the participant’s field of experience. This may be a limiting factor but it is also a necessity for a research project that is penetrating into the core of the issue to secure that the respective task is performed to highest possible standard. Thus the conclusion is that the right approach has been maintained.

The project has made a thorough examination of the chosen methods. The methods were carefully selected after the identification of the parameters to be measured for the soil characteristic determination. Mentioned is also the problem of comparability between different areas. Another identified factor of uncertainty is the calibration of both the instruments to be used and the values measured.

There is need for more development before a combined geophysical tool is available. Digisoil has shown that geophysics works and now the challenge will be to compile it into a “single” run measurement vehicle.

3.1.2. Comparability

There is need of a complete lattice or grid of information that is based on the same reference net. Once this is achieved it can be used for the extrapolation of new geophysical input to ensure that it is calibrated to the same level. This would also make it available for extensive correlation usage. The prevailing complexity of validation and calibration is making the methods comparably inaccessible for an end user.

Another issue that needs to be looked further into is the principle of equivalence. The possibilities of excluding potential equivalent interpretations are vastly enhanced by using a combination of methods that measures a property using different physical properties.

3.2. DATA PROCESSING REQUIREMENTS

One of the, if not the most, narrow bottleneck for the introduction of geophysics as a tool is the processing requirements. It raises the threshold to the final product to high levels. The use of the pedotransfert function within the processing sequence shows a lot of potential and can be further developed in order to reach a satisfactory end user functionality.

Pedotransforming geophysical units into soil characteristics will probably be the most immediate solution for the creation of an attractive product that is ready to be used.

There are gaps in the processing chain for smooth inversion / conversion of the geophysical data into soil characteristics. The principles have been established in the project but there is no “automated” computer assisted processing program available. The ultimate goal may be to create a user interface that would give the operator an initial idea already at the time of collecting the data. Geophysics have made large steps in that direction thanks to the use of digital techniques combined with computing power brought out in the field.

3.3. ADVANCEMENT OF TECHNOLOGY

The level of advancement is high in the project. For example geophysical methods that are just out of the cradle have been applied. This indicates that there is more research needed before the envelope of the method has been established.

3.4. REQUIREMENT OF FURTHER DEVELOPMENT

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 discussed 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. It should be kept in mind that the greatest interest has so far been documented to be towards the ready second order maps rather than making the measurements. Thus the level of development should maybe be geared towards a user category that has both the competence to run the surveys and to compile the maps.

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