



**HAL**  
open science

## **DIGISOIL: An Integrated System of Data Collection Technologies for Mapping Soil Properties**

Gilles Grandjean, Olivier Cerdan, Guy Richard, Isabelle Cousin, Philippe Lagacherie, Alain Tabbagh, Bas van Wesemael, Antoine Stevens, Sébastien Lambot, Florence Carre, et al.

► **To cite this version:**

Gilles Grandjean, Olivier Cerdan, Guy Richard, Isabelle Cousin, Philippe Lagacherie, et al.. DIGISOIL: An Integrated System of Data Collection Technologies for Mapping Soil Properties. Proximal Soil Sensing, Springer, pp.89-101, 2010, Progress in soil science, 978-90-481-8858-1 978-90-481-8859-8 978-94-007-3288-9. 10.1007/978-90-481-8859-8\_7 . hal-00548807

**HAL Id: hal-00548807**

**<https://brgm.hal.science/hal-00548807v1>**

Submitted on 20 Dec 2010

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

## Chapter 7

# DIGISOIL: An Integrated System of Data Collection Technologies for Mapping Soil Properties

G. Grandjean, O. Cerdan, G. Richard, I. Cousin, P. Lagacherie, A. Tabbagh, B. Van Wesemael, A. Stevens, S. Lambot, F. Carré, R. Maftai, T. Hermann, M. Thörnelöf, L. Chiarantini, S. Moretti, A. McBratney, and E. Ben Dor

**Abstract** The multidisciplinary DIGISOIL consortium intends to integrate and improve in situ proximal measurement technologies for assessing soil properties and soil degradation indicators, moving from the sensing technologies themselves to their integration and application in (digital) soil mapping (DSM). The core objective of the project is to explore and exploit new capabilities of advanced geophysical technologies for answering this societal demand. To this aim, DIGISOIL addresses four issues covering technological, soil science, and economic aspects: (i) development and validation of hydrogeophysical technologies and integrated pedogeophysical inversion techniques; (ii) the relation between geophysical parameters and soil properties; (iii) the integration of derived soil properties for mapping soil functions and soil threats; and (iv) the evaluation, standardisation, and industrialisation of the proposed methodologies, including technical and economic studies.

**Keywords** Soil properties · Sensing technologies · Geophysical techniques · Inference model · Water content

## 7.1 Introduction

The main objective of the European *FP7 Cooperation Work Program on Environment*<sup>1</sup> proposes to address global environmental issues in an integrated way by advancing our knowledge and capacities to develop new technologies for sustainable management of the environment and its resources. The DIGISOIL

---

G. Grandjean (✉)  
BRGM, Orléans, France  
e-mail: g.grandjean@brgm.fr

<sup>1</sup>Framework Program 7.

46 project started in autumn 2008. As with the iSoil project (Chapter 8), it is defined  
47 according to the FP7 work program and addresses ‘technologies for data collec-  
48 tion in (digital) soil mapping’. The multidisciplinary DIGISOIL consortium aims  
49 to integrate and improve in situ and proximal measurement technologies for the  
50 assessing soil properties and soil degradation indicators, moving from the sens-  
51 ing technologies themselves to their integration and application in (digital) soil  
52 mapping (DSM).

53 In order to assess and prevent soil degradation and to benefit from the dif-  
54 ferent ecological, economic, and historical functions of the soil in a sustainable  
55 way, there is an obvious need for high-resolution, accurate maps of soil proper-  
56 ties. The core objective of the project is to explore and exploit new capabilities of  
57 advanced geophysical technologies for answering this societal demand. To this end,  
58 DIGISOIL addresses four issues covering technological, soil science, and economic  
AQ2 59 aspects (Fig. 7.1): (i) the validation of geophysical (in situ, proximal, and airborne)  
60 technologies and integrated hydrogeophysical inversion techniques (mechanistic  
61 data fusion); (ii) the relation between geophysical parameters and soil properties;  
62 (iii) the integration of derived soil properties for mapping soil functions and soil  
63 threats; and (iv) the evaluation, standardisation, and industrialisation of the proposed  
64 methodologies, including technical and economic studies.

## 67 7.2 Objectives

68  
69  
70 The purpose of the DIGISOIL project is to identify and bridge the technological  
71 gap and develop pertinent, reliable, and cost-effective geophysical mapping solu-  
72 tions. Considering the new equipment and signal processing developments offered  
73 by recent scientific investigations, the problem of performing soil data collec-  
74 tions at the catchment scale using geophysical sensors can be foreseen in the near  
75 future, particularly for methods identified in the following tables (GPR, EMI, seis-  
AQ3 76 mics, magnetics, and airborne hyperspectral) (Tables 7.1 and 7.2). Gravity-based and  
77 thermal-based methods will not be incorporated in DIGISOIL because of their low  
78 contribution to the characterisation of soil properties related to degradation pro-  
AQ4 79 cesses. For gamma radiometrics, several investigations have already been carried  
80 out to study their potential for soil properties mapping (e.g. Viscarra Rossel et al.,  
81 2007). This technology has given satisfactory results and permits one to map types  
82 of clay minerals in the topsoil through the analysis of U, K, and Th anomalies  
83 in the gamma spectrum. We will not consider this method since it appears to be  
84 already used in the soil science community (Wilford and Minty, 2006). However,  
85 since the information provided by this technology has many interesting aspects, we  
86 will integrate it as potential auxiliary data in our mapping strategy. This context is  
87 therefore favourable for the development of DIGISOIL’s mapping tools and prod-  
88 ucts in relation to DSM applications. With respect to these issues, the milestones of  
89 the DIGISOIL project are  
90

7 DIGISOIL: An Integrated System of Data Collection Technologies

91  
92  
93  
94  
95  
96  
97  
98  
99  
100  
101  
102  
103  
104  
105  
106  
107  
108  
109  
110  
111  
112  
113  
114  
115  
116  
117  
118  
119  
120  
121  
122  
123  
124  
125  
126  
127  
128  
129  
130  
131  
132  
133  
134  
135

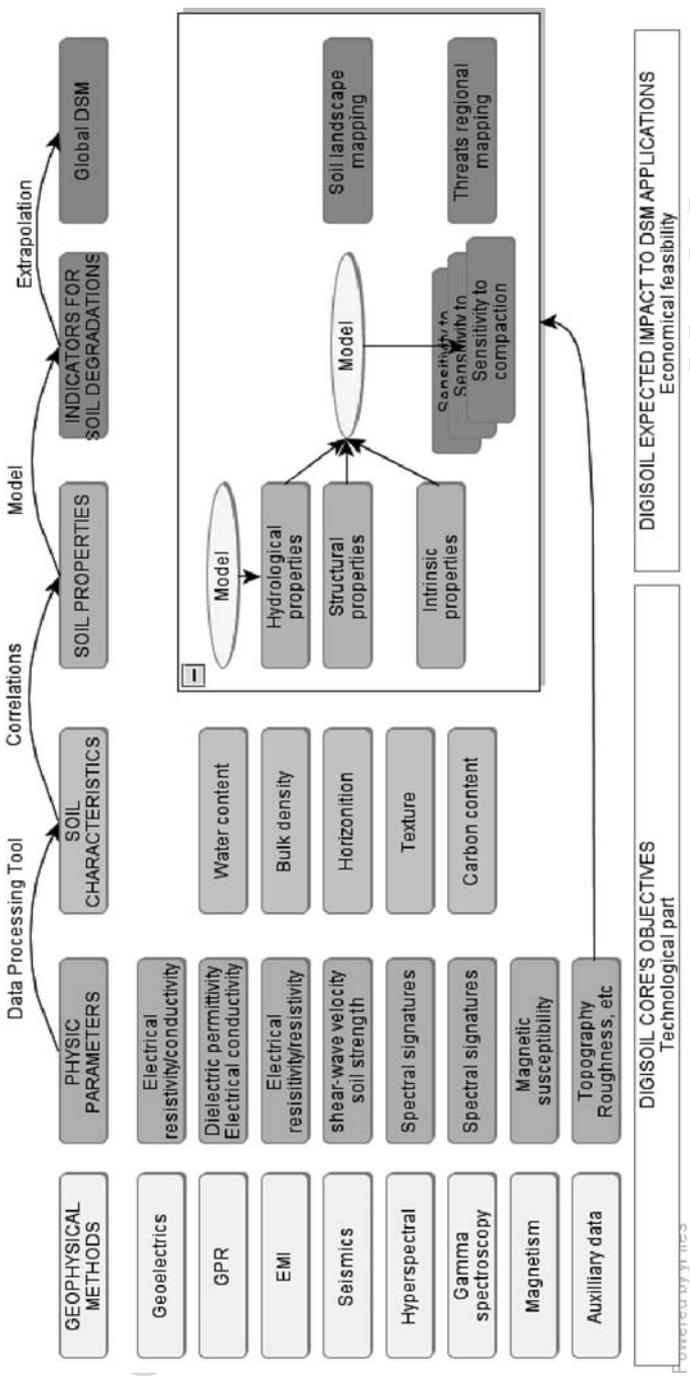


Fig. 7.1 DIGISOIL concept

**Table 7.1** Common elements for the identification of risk areas

136	<b>Table 7.1</b> Common elements for the identification of risk areas				
137	Soil threats				
138	<hr/>				
139	Soil erosion	OM decline	Compaction	Salinisation	Landslide
140	<hr/>				
141	<i>Soil properties</i>				
142	Soil texture	Soil texture/clay content	Soil texture	Soil texture	
143					
144	Soil density		Soil density		
145	Soil hydraulic properties		Soil hydraulic properties	Soil hydraulic properties	
146		Soil organic carbon	Soil organic matter		
147					
148					
149	<i>Soil-related parameters</i>				
150	Topography	Topography	Topography		Topography
151	Land cover	Land cover	Land cover		Land cover
152	Land use	Land use	Land use	Irrigation areas	Land use
153				Climate	
154	Climate	Climate	Climate	Climate	Climate
155	Hydrological conditions				
156	Agro-ecological zone				
157					
158					
159					Occurrence/density of existing landslides
160					
161				Groundwater information	
162					
163					Bedrock
164					Seismic risk
165	<hr/>				

165  
166  
167  
168  
169  
170  
171  
172  
173  
174  
175  
176  
177  
178  
179  
180

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 to end-user needs, their technical feasibility, and their cost-effectiveness.
4. To produce an exploitation plan including the standardisation of the processes and the technical specifications of the developed methodologies describing the system components in terms of equipment (sensors, acquisition system,

7 DIGISOIL: An Integrated System of Data Collection Technologies

**Table 7.2** Potential influence of soil threats on functions of soils

Function of soil/soil threat	Biomass production	Storing, filtering and transformation	Bio diversity pools	Physical and cultural media	Raw material	Carbon pool	Geological and archaeological heritage
Erosion	x	x	x	x	x	x	x
Decline in organic matter	x	x	x	–	x	x	–
Contamination	x	x	x	x	x	x	x
Sealing	x	x	x	x	x	x	x
Compaction	x	x	x	x	–	x	x
Decline in soil biodiversity	x	x	x	–	–	x	–
Salinisation	x	x	x	–	–	x	–
Floods and landslides	x	x	x	x	x	x	x

**x potential influence; – no influence**

mobile vector), techniques (signal processing, inversion or fusion processes, specialisation), and operational protocols.

### 7.3 Strategy and Workplan

The DIGISOIL architecture is structured according to five items in relation to the above-cited objectives of the project:

1. *Identification of pertinent sensor technologies:* the capabilities of the different geophysical techniques will be investigated and technically adapted so as to characterise highly complex soil properties (spatial and temporal heterogeneities, low variations of properties, context-dependant, etc.). Two series of experiments will be carried out with a two-step feedback approach in order to analyse sequentially, and on different sites, the quality of the results and the efficiency of each technology.
2. *The data integration for estimating soil properties:* the conversion of geophysical parameters into soil properties and the derivation of soil threats are not straightforward. Most of the time, several indicators are necessary to reduce the uncertainty of the estimation. Studying the different correlation between indicators and possible soil properties should finally lead to an innovative methodology of fusion, guaranteeing a final assessment in terms of soil diagnostics (soil properties, threats, and soil functions).
3. *Testing and validation on selected sites:* the Commission policies have to deal with various European environments. For that reason, the sensor technologies will be tested on two series of sites: (i) second-order test sites for a specific

226 technique adaptation and (ii) first-order sites for testing the validity domain of  
 227 different sensors at the same location. The latter have been selected in order  
 228 to ensure a maximal geographical representativeness within Europe. For this  
 229 validation task, classical in situ invasive sensors will be used.

230 4. *Evaluation of the proposed methodologies*: as the intent is oriented towards serv-  
 231 ing DSM applications, the results should be evaluated in terms of technical  
 232 feasibility, maturity, and economical costs.

233 5. *Exploitation of the proposed methodology*: with respect to the Work Program’s  
 234 objectives, which stipulate that technologies developed in the Collaboration  
 235 Program have to be finally exploited as European services, an exploitation  
 236 plan, including technical specifications of the developed methodologies, will be  
 237 presented.

241 **7.4 From Soil Threats to Geophysical Properties**

242  
 243 The DIGISOIL project can be seen as the setting up of operational techniques useful  
 244 for implementing existing and emerging EU environmental legislation and policy –  
 245 like the European Soil Thematic Strategy, which aims to protect soil functions and  
 246 prevent soil degradation. Table 7.3 represents the main soil and soil-related param-  
 247 eters to be considered by member states for delineating risk areas. Since soil texture,  
 248 soil water content, soil hydraulic properties, bulk density, and soil organic matter  
 249 are involved in many soil functions, these properties have to be considered the first  
 250 priority. Soils under threat cannot continue to perform all their environmental, eco-  
 251 nomic, social, and cultural functions in the same way after being degraded (e.g.  
 252 biomass production is not possible on sealed soils). The gradual loss of performance  
 253 of soil functions depends on the severity of a threat, which can be gauged in terms  
 254  
 255

256 **Table 7.3** Main ground-based and airborne geophysical methods and related physical parameters.  
 257 Italics indicate methods that will not be integrated into the DIGISOIL tool

258 Geophysical methods	Physical parameters
259 Ground-penetrating radar (GPR)	Dielectric permittivity, electric conductivity, magnetic permeability, frequency dependence of these electromagnetic properties
260 Seismic reflection and refraction	Volume and shear-wave velocities
261 Electromagnetic induction (EMI)	Electrical resistivity (electric conductivity and frequency dependence)
262 Electrical resistivity (geoelectric)	Electrical resistivity (almost zero-frequency)
263 <i>Gravity</i>	<i>Density</i>
264 <i>Magnetics</i>	<i>Magnetic susceptibility and viscosity</i>
265 <i>Airborne thermic</i>	<i>Surface temperature</i>
266 Airborne hyperspectral	Spectral reflectance
267 <i>Gammametry</i>	<i>Gamma spectrum (U, K, Th)</i>

## 7 DIGISOIL: An Integrated System of Data Collection Technologies

**Table 7.4** PLS regression output statistics of the best model for each dataset

Data	Calibration			Validation			
	N	RMSEC <sup>a</sup> g C kg <sup>-1</sup>	RMSEC/SD	N	RMSEP <sup>b</sup> g C kg <sup>-1</sup>	RPD <sup>c</sup>	R <sup>2</sup>
ASD	108	2.8	0.45	37	3.3	1.79	0.82
ASD <sup>d</sup>	77	1.7	0.25	24	2.4	2.33	0.90
CASI (Ortho)	94	3.0	0.93	32	4.4	1.08	0.44
CASI (Attert)	75	3.4	0.51	24	3.8	1.97	0.87
Casi+SASI	73	2.9	0.60	26	1.9	2.50	0.92

<sup>a</sup>Root mean square error of calibration

<sup>b</sup>Root mean square error of prediction

<sup>c</sup>Ratio of performance to deviation (RMSEP/SD)

<sup>d</sup>Only including the dataset of dry soil surfaces

of its intensity and duration. Depending on the type of threat, different soil functions may be affected (Table 7.4). In some cases more than one threat occur on a certain piece of land.

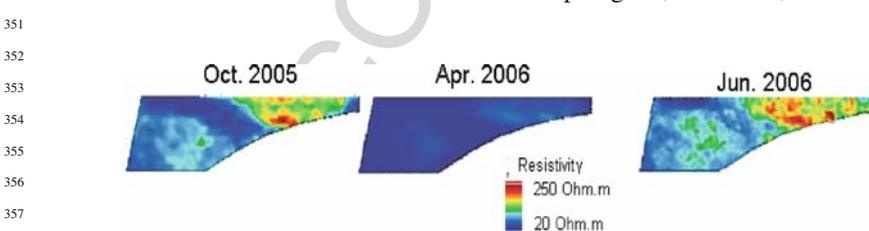
The combination of threats sometimes worsens their effect on soil functions. As illustrated in Fig. 7.1, which summarises the DIGISOIL concept, the core objectives of the program are focused on determining the most relevant soil properties, which in a second phase (and through the use of pedo- and hydro-models, as well as auxiliary data) will allow us to map soil threats and functions (Tables 7.3 and 7.4). In the last decades, geophysical prospecting applied to subsurface characterisation 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, working from the surface and from the air. 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. In a similar way, recent airborne geophysics has sparked strong interest due to the possibilities of civil airplanes equipped with optical, thermal, or hyperspectral sensors. The most common methods that take advantage of these enhancements, and their related parameters, are listed in Table 7.5.

Measuring the electrical resistivity of soil was proposed in the DIGISOIL project because it is closely related to several soil parameters and can be performed over areas of several hectares with high resolution (Panissod et al., 1997; Chapter 26, this volume). Up to now, the interpreting electrical measurements have remained difficult because the different influences soil parameters have on electrical resistivity are still hard to discriminate. There are numerous relationships between electrical resistivity and any one soil physical or chemical parameter. For example, there are

316 linear (or more complex) correlations between electrical resistivity and soil temper-  
 317 ature (Keller and Frischknecht, 1966), soil water content and salinity (Sen et al.,  
 318 1988), soil cationic exchange capacity (Shainberg et al., 1980), soil texture (i.e. clay  
 319 content), and soil porosity (Friedman, 2005). Other studies have demonstrated the  
 320 influence of soil structure on electrical resistivity, such as the impact of bulk density  
 321 or the effect of cracks (Samouëlian et al., 2003).

322 Spatial electrical investigations therefore enable us to describe soil structural  
 323 heterogeneity, with the aim of delineating specific zones for use in precision agri-  
 324 culture or to map soil texture (Tabbagh et al., 2000) or salinity (Corwin et al., 2006).  
 325 Nevertheless, despite these known relationships, it remains difficult to describe the  
 326 effect of ancillary parameters on electrical resistivity, especially the effect of the  
 327 soil structure (which changes quickly under the influence of water content and tem-  
 328 perature). To address these issues, specific experiments will be conducted in the  
 329 DIGISOIL project, such as taking measurements that should help describe the evo-  
 330 lution of at least one or two parameters (assuming the others remain constant). As  
 331 an example, Fig. 7.2 shows three electrical resistivity maps recorded at three dates  
 332 when only the soil water content was supposed to vary (Besson et al., 2008).

333 Other studies will evaluate the possibility of using field spectroscopy  
 334 (Chapter 11) to estimate carbon content (Stevens et al., 2006). Visible and near-  
 335 infrared (VNIR) spectral analysis and diffuse reflectance analysis are techniques  
 336 that can rapidly quantify various soil characteristics simultaneously (Ben-Dor and  
 337 Banin, 1995; Viscarra Rossel et al., 2006). There are three types of VNIR techniques  
 338 (Chapter 13), which operate at different spatial scales and in different environ-  
 339 ments: (1) laboratory spectroscopy (LS); (2) portable field spectroscopy (PS); and  
 340 (3) imaging spectroscopy (IS). LS and PS rely on ground-based sensors (such as  
 341 the Fieldspec Pro FR from Analytical Spectral Devices covering 350–2,500 nm).  
 342 IS uses air- or space-borne sensors such as the Compact Airborne Spectrographic  
 343 Imager or CASI (covering 405–950 nm) and the Shortwave Infrared Airborne  
 344 Spectrographic Imager (SASI), covering 900–2,500 nm). Two different test sites in  
 345 southern Belgium were monitored within the framework of the Belgian airborne  
 346 imaging spectroscopy campaigns under the PRODEX program. The aim was to  
 347 explore the capabilities of VNIR spectroscopy in the context of soil organic car-  
 348 bon (SOC) inventories and monitoring. The sites, Ortho in the Ardennes (50°8'  
 349 N, 5°36' E) and Attert (49°45' N, 5°44' E), were overflown with a CASI sensor  
 350 in October 2003 when cereal fields had been ploughed, harrowed, and reseeded.

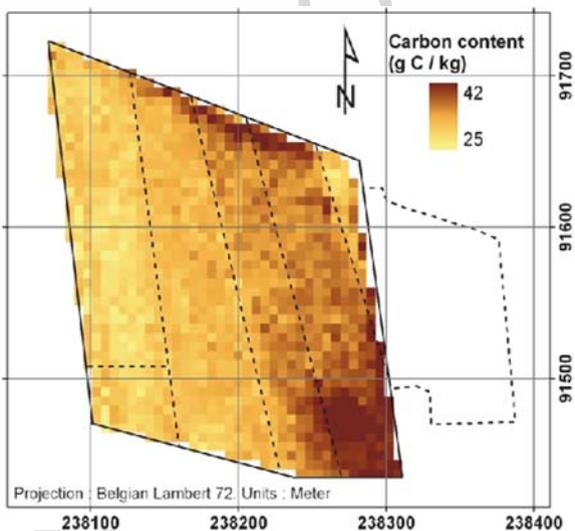


359 **Fig. 7.2** Resistivity maps for three dates showing the impact of water saturation in soils on  
 360 electrical resistivity (Besson et al., 2008)

## 7 DIGISOIL: An Integrated System of Data Collection Technologies

Exactly 120 soil spectra from 13 bare fields were taken at Ortho and 40 from 10 bare fields at Attert using the Fieldspec Pro (ASD). At the same sites, topsoil (0–5 cm) samples were taken and analysed for moisture content and organic carbon content (the latter by wet oxidation). Furthermore, three bulk density samples were taken in each field in order to calculate the SOC stock in the ploughed layer (mean thickness 22 cm). Another dataset from a previous IS campaign near Attert, using both CASI and SASI sensors, was also analysed. We used both stepwise and partial least square (PLS) regression analysis to relate spectral measurements to SOC content. Root mean square error of prediction (RMSEP) for the ASD ranged from 2.4 to 3.3 g C kg<sup>-1</sup> depending on soil moisture content of the surface layer (Table 7.4). Imaging spectroscopy performed poorly, mainly due to the narrow spectral range of the CASI. Tests using both the CASI and the SASI performed better. The variation in soil texture and soil moisture content degrades the spectral response to SOC contents. Currently, RMSEP allows us to detect an SOC stock change of 1.9–4.4 g C kg<sup>-1</sup> or 4.2–9.9 Mg C ha<sup>-1</sup> in the upper 22 cm of the soil and is therefore still somewhat high, at least in comparison with changes in SOC stocks resulting from management or land conversion reported in the literature (0.3–1.9 Mg C ha<sup>-1</sup> yr<sup>-1</sup>; Freibauer et al., 2004). A detailed SOC map produced by IS reflected the patterns in SOC content due to the site's recent conversion from grassland to cropland (Fig. 7.3).

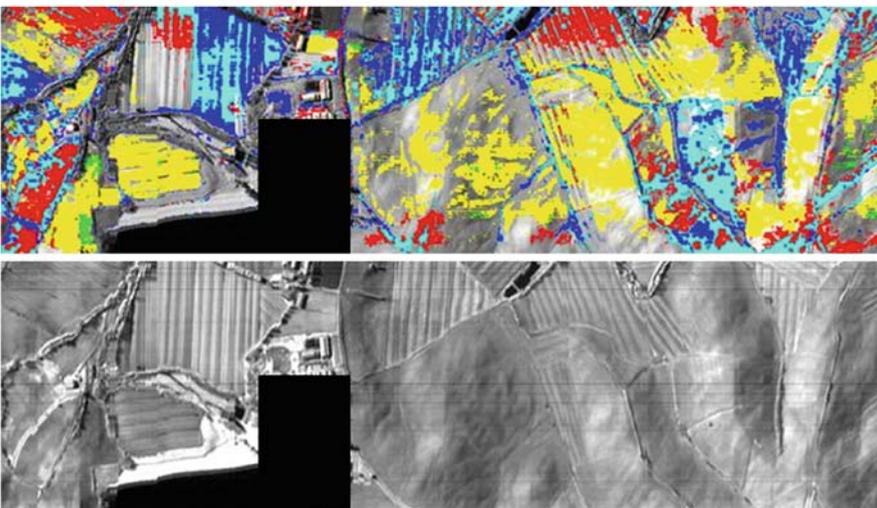
Accuracy of the spectral techniques is lower than that of most routine laboratory SOC analyses. However, the large number of samples that can be analysed by hyperspectral techniques outweighs the slight loss of precision compared to



**Fig. 7.3** Map of soil organic carbon content in a freshly ploughed field after land consolidation. The borders of the original fields that were joined are indicated with *dashed lines* (Stevens et al., 2006)

406 traditional chemical analyses. The greatest potential lies in airborne applications  
 407 because imaging spectroscopy can cover a wide region almost instantaneously and  
 408 produce thousands of samples. Relatively poor detection levels are attributed to sen-  
 409 sor characteristics (artefacts, noise, and limited spectral range) and factors affecting  
 410 the soil spectral response (limited variability in SOC content, disturbing factors).  
 411 The problem of disturbing factors will be addressed in the DIGISOIL project,  
 412 through an experimental study of the effect of soil moisture, soil texture, and soil  
 413 roughness on reflectance. Experiments on soil texture recovery, particularly well-  
 414 suited for distinguishing between calcite and clayed minerals and using ULM's  
 415 onboard sensors, have already begun (Fig. 7.4). Furthermore, specifications for air-  
 416 borne sensors as well as the optimal strategy for calibration and validation will be  
 417 documented.

418 Ground-penetrating radar (GPR) is an increasingly used non-invasive and  
 419 proximal electromagnetic (EM) sensing technology that can image the subsurface  
 420



447  
448 **Fig. 7.4** ULM facility and resulting images: one based on Spectral Angle Mapper (SAM) classifica-  
 449 tion; the second based on SWIR data where absorption bands of mineral clays (2.0–2.4  $\mu\text{m}$ )  
 450 are present (Univ. Firenze). *Red*: calcite, *green*: chlorite, *yellow*: illite, *blue*: illite-smectite, *cyan*:  
 smectite

## 7 DIGISOIL: An Integrated System of Data Collection Technologies

451 and identify its physical properties (Chapter 25). It is based on sending electromag-  
452 netic radiation (ultra-wideband VHF-UHF) into the soil and recording the reflected  
453 signals. In areas of agricultural and environmental engineering, GPR has been  
454 used to identify soil vertical structures, locate water tables, follow wetting front  
455 movement, identify soil hydraulic parameters, measure soil water content, assess  
456 soil salinity, monitor contaminants, and delineate soil compaction. Nevertheless,  
457 existing GPR techniques still suffer from major limitations due to simplifying  
458 assumptions on which they rely, particularly about EM wave propagation. In gen-  
459 eral, the radar system and antennas are not accounted for, ray approximation is  
460 applied to describe GPR wave propagation, and only the propagation time to reflect-  
461 tors is considered in signal processing algorithms. Reflection amplitude can also  
462 be used, but this is limited to the surface reflection for airborne GPR, and requires  
463 calibrations that are not practical for automated and real-time mapping. As a result,  
464 only a part of the information contained in the GPR data is usually used, and signifi-  
465 cant errors in the estimates are often introduced. To circumvent these shortcomings,  
466 Lambot et al. (2004) have recently developed a new approach: stepped-frequency  
467 continuous-wave monostatic off-ground GPR. The off-ground mode is particularly  
468 appropriate for real-time mapping of shallow subsurface properties. The radar sys-  
469 tem is based on ultra-wideband vector network analyser (VNA) technology. In  
470 contrast to classical GPR systems, the physical quantity measured by a VNA is  
471 exactly known and defined as an international standard. This permits the use of  
472 advanced full-waveform forward and inverse modelling techniques to estimate soil  
473 EM properties from the GPR signal, which intrinsically maximises information  
474 retrieval from the recorded data. In that respect, Lambot et al. (2004) developed  
475 a remarkably accurate EM model for their specific radar configuration, which  
476 included internal antenna and antenna–soil interaction propagation effects; they  
477 were able to exactly solve the three-dimensional Maxwell equations for wave propa-  
478 gation in multilayered media. Through GPR signal inversion, the approach has been  
479 successfully validated in a series of controlled hydrogeophysical experiments for  
480 electromagnetic soil characterisation (which included dielectric permittivity, elec-  
481 tric conductivity, and frequency dependence of these quantities). GPR data inversion  
482 has been also integrated with hydrodynamic modelling to retrieve soil hydraulic  
483 properties from time-lapse radar data and to monitor the dynamics of continuous  
484 water content profiles (Lambot et al., 2006). In addition, the technique improves  
485 shallow subsurface imaging, which represents an important asset for determining  
486 high-resolution soil stratigraphy. Figure 7.5 shows an example of a field applica-  
487 tion where the developed method is used for real-time mapping of the soil surface  
488 dielectric permittivity and correlated water content, bridging the spatial scale gap  
489 between traditional soil sampling and remote sensing in hydrology.

490 To complement the above-cited techniques, DIGISOIL aims also to explore inno-  
491 vative geophysical methods for characterising specific soil properties. In particular,  
492 seismic methods will be tested in order to quantify the soil's mechanical modulus, a  
493 parameter closely related to soil compaction (Grandjean, 2006). Already validated  
494 in geotechnics for investigating zones tens of metres in extent, the challenge will be  
495 in adapting the methodology to small seismic devices, i.e. zones of several metres.

This figure will be printed in b/w

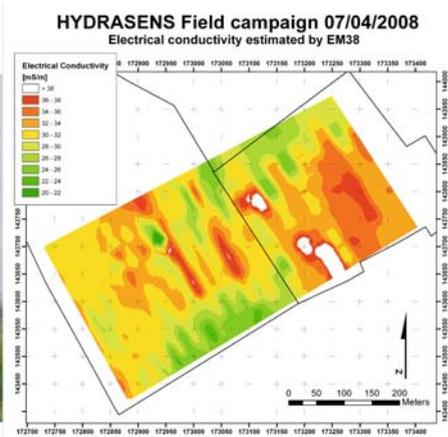


Fig.7.5 Real-time mapping of soil surface water content with advanced GPR (Lambot et al., 2006)

## 7.5 Conclusions

In order to assess and prevent soil degradation, and to benefit from the different ecological, economic, and historical functions of the soil in a sustainable way, there is an obvious need for high-resolution, accurate maps of soil properties. The core objective of the project is to explore and exploit new capabilities of advanced geophysical technologies for answering this societal demand. Some geophysical techniques that will be carried out in the project are based on positive experiences in the domain and promise to fulfil the objectives of the project. Electrical and GPR measurements, hyperspectral imagery, and more innovative methods like seismic methods will be tested and technically adapted to soil properties mapping. An important output of the project will concern the use of related soil properties in an application dedicated to digital soil mapping (Chapter 5).

**Acknowledgement** The DIGISOIL project is financed by the European Commission under the 7th Framework Program for Research and Technological Development, Area 'Environment', Activity 6.3 'Environmental Technologies'.

## References

- Ben-Dor E, Banin A (1995) Near infrared analysis (NIRA) as a rapid method to simultaneously evaluate several soil properties. *Soil Sci Soc Am J* 59:364–372
- Besson A, Cousin I, Bourennane H, Pasquier C, Nicoullaud B, Richard G, King D (2008) Discretization of spatial and temporal soil water variability into homogeneous zones based on electrical resistivity measurements at the field scale. EUROSOIL congress 2008, Soil, Society, Environment, 25-29/08/2008, Vienna
- Corwin DL, Lesch SM, Oster JD, Kaffka SR (2006) Monitoring management-induced spatio-temporal changes in soil quality through soil sampling directed by apparent electrical conductivity. *Geoderma* 131:369–387

## 7 DIGISOIL: An Integrated System of Data Collection Technologies

- 541 Freibauer A, Rounsevell MDA, Smith P, Verhagen J (2004) Carbon sequestration in the agricultural  
542 soils of Europe. *Geoderma* 122:1–23
- 543 Friedman SP (2005) Soil properties influencing apparent electrical conductivity: a review. *Comput*  
544 *Electron Agric* 46:45–70
- 545 Grandjean G (2006) A seismic multi-approach method for characterizing contaminated sites. *J*  
546 *Appl Geophys* 58:87–98
- 547 Keller GV, Frischknecht FC (1966) *Electrical methods in geophysical prospecting*. Pergamon,  
548 Oxford
- 549 Lambot S, Slob EC, van den Bosch I, Stockbroeckx B, Vanclooster M (2004) Modeling of ground-  
550 penetrating radar for accurate characterization of subsurface electric properties. *IEEE Trans*  
551 *Geosci Remote Sens* 42:2555–2568
- 552 Lambot S, Slob EC, Vanclooster M, Vereecken H (2006) Closed loop GPR data inver-  
553 sion for soil hydraulic and electric property determination. *Geophys Res Lett* 33:L21405,  
554 doi:10.1029/2006GL027906
- 555 Panissod C, Dabas M, Jolivet A, Tabbagh A (1997) A novel mobile multipole system (MUCEP)  
556 for shallow (0–3 m) geoelectrical investigation: the ‘Vol-de-canards’ array. *Geophys Prospect*  
557 45:983–1002
- 558 Samouëlian A, Cousin I, Richard G, Tabbagh A, Bruand A (2003) Electrical resistivity imaging  
559 for detecting soil cracking at the centimetric scale. *Soil Sci Soc Am J* 67:1319–1326
- 560 Sen PN, Goode PA, Sibbit, A (1988) Electrical conduction in clay bearing sandstones at low and  
561 high salinities. *J Appl Phys* 63:4832–4840
- 562 Shainberg I, Rhoades JD, Prather RJ (1980) Effect of ESP, cation exchange capacity and soil  
563 solution concentration on soil electrical conductivity. *Soil Sci Soc Am J* 44:469–473
- 564 Stevens A, van Wesemael B, Vandenschrieck G, Tychon B, Touré S (2006) Detection of car-  
565 bon stock change in agricultural soils using spectroscopic techniques. *Soil Sci Soc Am J*  
566 70:844–850
- 567 Tabbagh A, Dabas M, Hesse A, Panissod C (2000) Soil resistivity: a non-invasive tool to map soil  
568 structure horizonation. *Geoderma* 97:393–404
- 569 Viscarra Rossel RA, Walvoort D, McBratney AB, Janik L, Skjemstad J (2006) Visible, near  
570 infrared, mid infrared or combined diffuse reflectance spectroscopy for simultaneous assess-  
571 ment of various soil properties. *Geoderma* 131:59–75
- 572 Viscarra Rossel RA, Taylor HJ, McBratney AB (2007) Multivariate calibration of hyperspectral  
573 gamma-ray energy spectra for proximal soil sensing. *Eur J Soil Sci* 58:343–353
- 574 Wilford J, Minty B (2006) The use of airborne gamma-ray imagery for mapping soils and under-  
575 standing landscape processes. In: Lagacherie P, McBratney AB, Voltz M (eds) *Digital soil*  
576 *mapping: an introductory perspective*. Elsevier Science, Amsterdam, 600 pp
- 577  
578  
579  
580  
581  
582  
583  
584  
585