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A web based spatial decision supporting system for land management and soil conservation

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Abstract

Today it is evident that there are many contrasting demands on our landscape (e.g. food security, more sustainable agriculture, higher income in rural areas, etc.) but also many land degradation problems.

It has been proved that providing operational answers to these demands and problems is extremely difficult.

Here we aim to demonstrate that a Spatial Decision Support System based on geospatial cyber-infrastructure (GCI) can embody all of the above, so producing a smart system for supporting decision making for agriculture, forestry and urban planning with respect to the landscape.

In this paper, we discuss methods and results of a special kind of GCI architecture, one that is highly focused on soil and land conservation (SOILCONSWEB-LIFE+ project). The system allows us to obtain dynamic, multidisciplinary, multiscale, and multifunctional answers to agriculture, forestry and urban planning issues through the web. The system has been applied to and tested in an area of about 20 000 ha in the South of Italy, within the framework of a European LIFE+ project.

The paper reports – as a case study – results from two different applications dealing with agriculture (olive growth tool) and environmental protection (soil capability to protect groundwater).

Developed with the help of end users, the system is starting to be adopted by local communities. The system indirectly explores a change of paradigm for soil and landscape scientists. Indeed, the potential benefit is shown of overcoming current disciplinary fragmentation over landscape issues by offering – through a smart web based system – truly integrated geospatial knowledge that may be directly and freely used by any end user (www.landconsultingweb.eu). This may help bridge the last much important divide between scientists working on the landscape and end users.

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1 Introduction

1.1 The land management and soil conservation problem

Land management and soil conservation issues are closely connected to the complexity of our societies. It is evident today that many of the following contrasting pressures coevolve upon our landscape: increasing pressure from the human population, increasing demand for a better environment, increasing demand for more sustainable agriculture, increasing demand for food security, increasing demand for higher income in rural areas, etc.

On the other hand, there are many problems affecting our landscape, such as the evident land and soil degradation processes that are unevenly spread across the landscapes of many countries, as well as the very limited awareness of the importance of landscape and soil to our societies.

Moreover, many strategic high policy expectations recall these concepts; for instance by emphasizing the need to combine productivity with more sustainable landscape management, such as in (i) FAO new Strategic Objectives, (ii) Horizon 2020, (iii) The United Nations' Sustainable Development Goals.

However, this general agreement on the part of policy makers does not always correspond to tools being made available to render this policy goal feasible.

Indeed, there are many problems in making these concepts truly operational since providing an answer to all the above demands together with suitable landscape/farm planning and managing can be very complex. Some examples of these difficulties are:

1. Difficulties of farmers, farmer associations, municipalities, province, regions or countries in dealing with the multifunctional role of soil and landscape;
2. The need to provide answers to multi-user/multi-stakeholder communities;
3. Limitation of classic top-down approaches to carrying out soil and landscape management and the subsequent high expectation in supposed integrated

governance approaches, including bottom-up contributions by a large spectrum of landscape users and stakeholders;

4. Cultural and technical problems due to the great complexity of agricultural, forestry environmental challenges (e.g. nitrate leaching);
5. Technical problems regarding the lack of both suitable geospatial databases and technical/scientific support to render these databases useful for decision making;
6. Data quantity/quality variance in space. This leads to heterogeneous geodatabases and fundamental requirements for easy updating of both databases and models.
7. Difficulties in quantifying the functions and ecosystem services of soils (e.g. food and other biomass production, storing, filtering and transformation, habitat and gene pool, physical and cultural environment for humankind, and source of raw materials);
8. Difficulties in quantifying soil threats (erosion, landslides, floods, soil sealing, diminishing organic matter, etc.);
9. Last, but not least, many agriculture and environmental issues require, as a "must", dynamic answers which vary in time and space (over the landscape). This case is clearly shown in Table 1, which analyzes soil and landscape policy requirements, such as those reported in some important EU regulations/directives, together with their dynamic requirements.

In real life, there is an additional problem. Scientific communities which are supposed to address and, eventually, solve many of the above problems are not always predisposed to developing their work within an integrated operational approach. Therefore we claim here that it is essential to do something different.

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1.2 The Spatial Decision Support approach to addressing the land management and soil conservation problem

We suggest that advanced "Spatial Decision Support Systems" (SDSS) may be of great help in facing these problems. We also claim that well diffused visualization tools – such as the standard WEB-GIS system – are simply not able to address the above challenges well enough.

SDSS already has its own short history (Geertmanand Stillwell, 2009), with successes, but also many failures due to the development of very complex systems which are both difficult to operate and difficult to modify. Therefore, it is important here to refer to some examples which appear to be best cases for SDSS operating in the field of agriculture and environment.

In fact, SDSS (or differently named very similar systems) have been developed for many different issues including: (i) accessing forest resource data on a variety of scales (McInerney et al., 2012), (ii) a system for the sustainability of agriculture in a pilot study in Tanzania (Fegraus et al., 2012), (iii) web service for exploring geospatial cropland data in United States (Han et al., 2012), (iv) supporting fertilization for farmers in the Northeast of China (Xie et al., 2012), (v) land use planning and local forestry development under different scenarios of the carbon credit market (Wang et al., 2010), (vi) scheduling deficit irrigation by using the CropSyst model (Marsaland Stockle, 2012), (vii) simulating stream water quality conditions (nitrate and phosphorous) in different scenarios (Booth et al., 2011), (viii) regional risk assessment (including socioeconomic data) for contaminated sites (Agostini et al., 2012).

It is also very important that there are some cases where SDSS have been produced by incorporating scalable approaches (Stewart and Purucker, 2011; McInerney et al., 2012) and an integrated crop and soil database system (Yang et al., 2011) to enable efficient modelling and the use of Multicriteria SDSS analysis (Agostini et al., 2012; Bottero et al., 2013). In other cases, DSS integrated systems have been developed to

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assess climate change over land use (Wenkel et al., 2013) but these are not as yet operational for the web.

In SDSS, the web interactive thematic cartography method for public participation is more often found in urban planning (Zeng et al., 2013).

Only in rare cases – namely outside the area of agriculture and environment – do we find reported the use of fully operational “what if modelling” engines in SDSS systems (Santos et al., 2011), which take hypothetical changes in the application variables or parameters as a input and estimate its impact on performance.

These papers relating SDSS on agriculture and environment clearly show the importance and the rapid, positive progress of this research topic. On the other hand, we must emphasize here that most of the above contributions are somehow sectorial since they focus on a specific topic and, moreover, they do not incorporate the crucial dynamic nature of some environmental data. For instance, this is the case for their climate models, in which the daily climate variation – which is indeed a key issue in many agriculture environmental applications – is simply missing.

Therefore – considering the actual complexity of many current agricultural and environmental challenges – we claim here that there is the need for a very different, much more integrated and operational approach (through the web) which will hopefully incorporate all of the features reported in Fig. 1. Is this system feasible however? We believe that recent scientific and technological progress and the great improvement in databases make it possible to move down a new road.

This progress refers to (i) current developments in the availability of spatial Data (complex, multiscale, long term, etc.), (ii) Digital Soil Mapping engines, (iii) simulation modelling of the SPA (Soil–Plant–Atmosphere) system, (iv) open source Web-GIS, (v) High Performance Computing and, especially, GPU processing, (vi) moreover recent developments in Web based “geospatial cyber-infrastructure” (GCI) platforms promise to produce efficient and performing SDSS. Indeed, the GCI platform can support the acquisition, storage management and integration of both advanced and dynamic data (e.g. pedological, daily climatic, and land use); data mining, data visualization;

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computer “on-the-fly” applications in order to perform simulation modelling (e.g. soil water balance and crop growth), all potentially accessible via web.

1.3 The aim of this research

Thus, the general aim of this contribution is to demonstrate that GCI-SDSS systems can embody all of the above, so producing a smart multidisciplinary integrated geospatial knowledge system for the landscape to support decision making in agriculture, forestry and urban planning.

In order to show the system in operation, this paper also aims to illustrate – as case studies – two very different specific applications – namely olive growth and groundwater protection.

All the above have been achieved within the framework of the EU LIFE+ SOILCONSWEB project.

2 Materials and methods

2.1 The study site

The work was performed in the “Valle Telesina” site in South Italy (Fig. 2). The area is of about 20 000 ha; it is close to the city of Benevento and encompasses 13 municipalities. It is a very complex landscape with a high soil and climate spatial variability.

The Valle Telesina has a composite geomorphology and an east–west elongated graben where the Calore river lies. Five different landscape systems are present (Fig. 2): (i) limestone mountains, with volcanic ash deposits at the surface, (ii) hills, comprised of marl arenaceous flysch, (iii) pediment plain, comprised of colluvium material from the slope fan of the limestone relieves, (iv) ancient alluvial terraces and (v) the actual alluvial plain. Such complexity is echoed in the 60 Soil Typological Units, aggregated into 47 Soil Mapping Units.

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The study area is traditionally suited to the production of high quality wine (Bonfante et al., 2011) and olive oil in the hilly areas, while beech and chestnut forests are present in the mountain system, where there is a natural park. It is also important to emphasize the fact that, over the last decade, the "Valle Telesina" has experienced a large amount of soil consumption as a result of land use change due to new urbanization. These changes in land use have caused conflicting interests, between agriculture-forestry-urbanization, and ideas of how the land should be used.

2.2 The architecture design of the SOILCONSWEB-GCI: methodological and technological issues

The basic architecture of the SOILCONSWEB-GCI was developed by using free open-source geospatial libraries and programs. Here we describe the main methodological and technological issues relating to both the open source approach and its capacity to allow users to interact with the environmental and agricultural data on the map directly via web.

The chosen logical architecture is 3-tier. It is a client–server architecture in which the presentation, the application processing, and the data management are logically separate processes. The presentation tier displays information relating to the services, the business logic tier controls the application's functionality by performing detailed processing and, finally, the data tier consists of a database where information is stored and retrieved in such a way as to keep data neutral and independent of application servers or business logic. The main advantages in the use of the 3-tier architecture are that: (i) complex rules are easy to implement in application servers, (ii) business logic is off-loaded from database servers and clients, which improves performance, (iii) changes to business logic are enforced automatically by servers – changes only require new application server software to be installed, (iv) application server logic is portable to other database server platforms by virtue of the application software.

Technological details are shown in Fig. 3 (further explanations are given in the results section). Fundamentally, client-server communication is based on AJAX

(Asynchronous Java Script and XML) technology and most of the data are transferred from the server to the client in JSON format. The graphs are presented in the user interface using YAHOO Charts as a part of the ExtJS library. AJAX can deliver effective results in terms of user experience and opens up opportunities for further developments.

According to 3-tier architecture and AJAX technologies, on the web client have been implemented the presentation tier and a fraction of the business logic tier developed using the Java Script library. The main frameworks used to display and inquire into the geodata were Open Layers and ExtJsandGeoExt. OpenLayers is an open source (provided under a modified BSD license) JavaScript library for displaying map data on web browsers which provides APIs (application program interfaces) for building rich web-based geographic applications. SenchaExtJs is one of the fastest JavaScript Libraries that allows web building applications with a rich set of user widget and data structures. GeoExtis an extension of ExtJs and links ExtJs and OpenLayers, adding new widgets. In addition, a layer of custom code, which uses the listed frameworks and implements the user interface and a part of the business logic, has been written in JavaScript.

On the server side, the system uses the following extensive technologies: PHP; APACHE Web SERVER; PostgreSQL + PostGIS, and GeoServer, as well as some more specialized technologies such as FPDF (PHP class which allows the generation of PDF files with pure PHP). In order to meet project and user demands, the development of the system required the implementation of new functionalities. In particular, on the basis of the current state of art of the vector data elaboration, PostGISfunctions was used to conduct the innovative vector analysis. Indeed, PostGIS shows interesting characteristics for data extraction from one or more vector layers (such as intersections and overlaps) and massive processing of statistical raster data. Besides PostGIS, a very new approach was used to process raster data by combining original C++ code Raster Algebra and PostGIS functionality. Accessing raster data (reading and writing) was carried out by GDAL library, which abstracted the access data in various formats, while accessing vector data was carried out by the pqxx (a C++ library for accessing PostgreSQL databases). A notable example is a massive, fast ZonalAttribute operation on a large layer stack of raster data (mean statistical values extraction/variance/minimum/maximum/pixel count). This allows the analysis of a large number of a raster files with a polygon shape file masking (both optional), where the pixels positioning (inside or outside the polygon) is carried out by PostGIS functions. In other words, via PostGIS, the system decides what the segments (and thus the pixels) of a raster line which belongs to a selected polygon are. The ZonalAttribute is a recurrent algorithm which is used to extract statistical data from raster data in order to run many tools within our system. Another unique characteristic is a module that uses a port of the SWAP software (Soil–Water–Atmosphere–Plant, originally written by Alterra and Wageningen University, Kroes at al., 2008) for Linux to perform real time simulations on water balance in the soil-plant-atmosphere continuum.

A key technical issue in the SOILCONSWEB-GCI is the Browser-based JavaScript framework OpenLayers, which provides the capacities to view, query and render thematic layers and related information that is served from WMS and WFS layers (within one map widget) as images. Indeed, a specific functionality of the map viewer is its ability to connect to a wide range of WMS servers by using a WMS end-point (either a single layer or entire service). In SOILCONSWEB-GCI, we use a Geoserver server to provide WMS and WFS services to the client application.

2.2.1 Dataset

The dataset included data and metadata from many different sources – given in Table 2. Data are an essential component of the system and some data are parameters for feeding many GCI models. The main types of geo-referenced data include the following (i) static data (e.g. thematic databases) dealing with agriculture and environment, (ii) static data obtained from measurements obtained by field specific survey activities (e.g. soil hydrology), (iii) dynamic data obtained by automated climate stations, (iv) measurements obtained by remote sensing (e.g. forestry ground biomass stock).

Mapping data (fulfilling the INSPIRE directive) varied in many technical features and this required a special effort in data harmonization in order to make the whole GSI-SDSS work. The main problems encountered were the following: (i) data resolution of different thematic layers varied greatly in both spatial and temporal domains, (ii) large heterogeneity of data type (e.g. for geology, population, soil, water storage, biodiversity, etc.), (iii) data quality heterogeneity (gaps in data were rather common in thematic information), (iv) legal restrictions regarding data to be displayed on the web (e.g. variations between different data), (v) structure of data varied greatly (text files, .shp, .grid, qualitative information, etc.).

In general terms, the following preprocessing was required to incorporate data into our SOILCONSWEB-GCI. All of the spatial data, namely vector and raster layers (i.e. preexisting thematic maps, remote sensing data, etc.), at landscape level were re-projected into the local UTM zone 33, datum WGS84. They were checked for anomalies and subjected to up-scaling procedures where required (for instance this was required for high resolution data for specific application). Vector data were verified for the information they contained and redundant data were eliminated (i.e. landscape system maps may have contained information about soils which was already present in the soil maps). Land use maps which referred to different projects or different periods were harmonized if required for specific applications (e.g. land cover Touring, 1954, and Corine, 2006, had different classification structures).

Point data, such as those from soil sampling campaigns and forest stand surveys, were checked for anomalies (i.e. spatial coordinates, missing data, etc.). A unique ID was assigned for each type of data (i.e. the codes of soil horizons had to match those of corresponding hydraulic properties).

All data, except for those subsequently used for the spatial interpolation procedures (see later), were clipped within the study area.

As regards remote sensing data, the wet season data for the 18 December 2008 to 6 March 2009 time span were obtained by SPOT and Landsat platforms and the dry season, 18 June 2009 to 6 September 2009, data came from the RapidEye, IKONOS and GeoEye platforms. DEIMOS time series data covered the wet and dry seasons of 2012. Training data were collected from Worldview-2 scenes and the MODIS time series was classified by using a decision tree.

The architecture provides a service that relies on metadata which are specific to the shared resources. It is an essential component that helps in both resource dissemination and resource locating. One of the advantages of such a service is undoubtedly its ability to link the need to highlight these inherent data to the producers and the final users, who access system resources at their location. According to this vision, all metadata comply with INSPIRE (COMMISSION REGULATION (EC) No 1205/2008 of 3 December 2008 implementing Directive 2007/2/EC of the European Parliament and of the Council as regards metadata).

Primary and derived data were loaded into the geospatial database (i.e. PostgreSQL plus PostGIS in the Database tier of Fig. 3). The geospatial database allows location queries (run in SQL), so adding support for geographic objects. This required database harmonization in order to account for differences between data. Some datasets turned out to be significantly richer and more complex (e.g. soil mapping) than others and required additional data processing. Quality control assessments were required in order to ensure that database accurately reflected data types, field survey data, etc. This was done to ensure that data contained as few coherency, integrity and quality issues as possible. Lastly, geo-referenced photographs and associated metadata, from field surveys, were also stored on the file system according to the sampling location and associated field description (e.g. site and soil profile morphology).

2.2.2 Models: basic methodological issues

The complexity of the SOILCONSWEB-GCI system is due to the need to assess and analyze the multi-functional role of soils and landscape. This requires the use of a set of models that is capable of evaluating ecosystem services and functions; thus, we had to use different models depending on the type of issue to be tackled, state of the art, data

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availability, calculating and processing capacity, degree of testing (and acceptance) by the scientific community and availability of source code.

Consequently, it should be no surprise if, in the SOILCONSWEB-GCI system, we employed all the following: physically based models, empirical models and other in-between models.

The implementation of models in the GCI sometimes consisted of writing a few lines of program code (e.g. Table 3). On the other hand, in other cases it consisted of writing large programs ex-novo (such as WeatherProg and cvSISE) or struggling to recompile pre-existing programs on different platforms from those which they were built and tested for (e.g. SWAP).

In general terms, models in the SOILCONSWEB-GSI system were selected bearing in mind future development in new areas. This meant the formulating of problems with a high level of generalization while keeping local empirical approaches as low as possible. In this framework, we selected models which use the following criteria: (i) where possible, attempting to privilege physically-based core engines, (ii) coherence with available databases (Terribile et al., 2011), (iii) coherence with the modular structure, (iv) easily interchangeable routines at own convenience (e.g. evapotranspiration, water balance), (v) propensity to include new routines, (vi) possibility to switch the different modules on or off, in accordance with the requirements of the wrapping application, (vii) potential facilities for extensive validation (on the ground or through remote sensing) and potential assimilation of new remote-sensing data, (viii) ease in creating/managing different scenarios (what-if modelling); (ix) real time or quasi-real time spatial inference modelling; (x) compliancy with the Open Geospatial Consortium specifications.

2.2.3 Dashboards: basic methodological issues

The need to address a number of on-line applications required the development of a decision support dashboard for every type of user (each user has very different

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knowledge). Indeed, a single dashboard for all users with many very different tools would create confusion.

The dashboard design had to include graphical tools, procedures to combine spatial data (analysis and visualization) and the production of tables and maps. Moreover, the dashboard also had to enable the activation of algorithms based on different programming languages, databases, graphics packages, architectures, etc. However, all this diversity and complexity of information and processing, even though well documented for the user (full documentation is supplied), had to be hidden in its practical use (transparent to the user). Indeed, the dashboard had to enable easy and intuitive navigation and, above all, it had to make the user happy to operate it and, possibly, it had to remind the user of something that he already knew (visualization, procedures, etc.).The importance of this caution in dashboard planning was a real must and should not be minimized. Indeed, it is evident that this specific feature traces the border between a system that has potential success and a similar one with definite failure.

In the scientific literature, there are many examples of dashboards in different contexts which have been implemented for a very large number of different areas (Sjobergh and Tanaka, 2014; Kijewski-Correa et al., 2014) including sustainable development, tourism, public health, hospital management, etc. Their analysis can be very useful, but any dedicated dashboard has to be calibrated and adapted to a certain type of user (and his own level of knowledge).

Our final result had to be a unique, intuitive, easy to understand/follow dashboard which allowed the user to obtain support for his decisions about the landscape, soil and environment. To achieve this objective, specific meetings were organized for each type of end user/stakeholder (2–3 meetings/groups) in order to identify which modules and sub-modules might be the most important and which would be the best outlining and architecture menu.

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3 Results

The criteria for developing the specific Geospatial CyberInfrastructure (SOILCONSWEB-GCI) were indicated above. Therefore, the general objective is to generate solutions for supporting decision making in terms of agriculture, forestry, urban planning and landscape awareness by developing integrated algorithmic approaches for the analysis of the physical landscape. We aimed to achieve this general objective through approaches which are transparent to the end user. The system is accessible at www.landconsultingweb.eu.

We report the main findings of the SOILCONSWEB-GCI in two separate sections. The first section describes the complex GCI architecture that allows the multifunctional applications of the system; the second section describes the application of the system for (i) olive growing, in an Agriculture/Forestry context and (ii) soil capability to protect groundwater pollution in an Environmental protection context.

3.1 The Implementation of the SOILCONSWEB geospatial cyber infrastructure (GCI)

3.1.1 Implementation logic

The end-to-end GCI architecture and operating mode of SOILCONSWEB project is presented in Fig. 3 (CGI core workflow), where the interaction between the three tiers and the workflow between system components can be observed. A core workflow is where different types of project data feed different server functions (e.g. models), which in turn produce a set of applied and basic server services that lastly can be accessed by the dashboard.

One key and interesting point is the AOI (area of interest) drawing tool by which the user (e.g. farmer) can delimit the region of interest (e.g. the farm) within which he can run any implemented tool. In the system, there is a menu enabling the user to explore several possibilities of AOI data input. Indeed, applications typically activate

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algorithm processing for the polygon (closed arc), which is free-drawn on-line by the users (by clicking on geographical points) or selected by using preexisting polygons (e.g. municipalities, cadastral registry land inventory). The AOI may also consist of a number of polygons. Moreover, the AOI might be (i) re-edited/deleted, (ii) stored in a personal space, (iii) made public for general use. All of this is visualized by automatically displaying the arc defined by users on a map. Once drawn, the AOI represents key data stored in a database and linked to the user.

In order to perform the highly complex multifunctional applications on the AOI, it is mandatory that SOILCONSWEB-GCI integrates raw data, data management, data analysis capabilities and graphical display capacities into a system that is perceived of as “easy to use”. All of these issues, along with the spatial nature of the data, led us to develop the SOILCONSWEB-GCI platform by using Google Maps as a basic visualization layer, because of its large use by local communities. On this basis, SOILCONSWEB-GCI incorporated the state-of-the-art optimization algorithms.

3.1.2 Functions

The complex multifunctional and multi-stakeholder tasks required by the SOILCONSWEB-GCI system demanded the use of a set of functions (Fig. 3-Functions) and, especially, models that are capable of evaluating ecosystem services over the AOI. In accordance with the specific questions to be answered, these multifunctional models range from the physically based to merely empirical.

In general terms, models consist of custom processing routines that have been developed within Geoserver, custom low level programming language codes (such as C, C++ or FORTRAN), and processing scripts in the R Statistical Language or MATLAB. These analytical efforts were required to address answers to the ecosystem services/function given in Table 1.

All the models used in the SOILCONSWEB system are part of a modelling chain and the principle features of each of the main models are given in Table 3. The modelling chain includes:

- 1st level models referring to basic functions such as spatial inference and zonal statistics of basic environmental variables (e.g. soil, climate);
- 2nd level models, which require 1st level models as an input and refer to the basic functioning of the soil–plant–atmosphere system;
- 3rd level models which refer to applications. These typically require 1st and/or 2nd level models as inputs.

Below a brief overview of selected models is given in order to clarify how SOILCONSWEB functions.

1st level models

These include core engines, newly written programs, for the spatial inference of basic environmental attributes, in this case climatic variables and soil properties. These fully customized programs provide the spatial and dynamic components to our GCI and populate the 2nd and 3rd modelling levels.

Digital climatic mapping
Climatic data are some of the most important basic information within our GCI. WeatherProg was developed on the basis of previous work (Langella et al., 2010) and is the baseline asynchronous engine for handling the raw weather records within our project (Langella, 2014). The automatic managing of data spans from the raw signals registered by the sensors to the making of digital maps on both hourly and daily time scales. The key objective is to make spatial predictions and build basic informative layers for the various diverse requirements of the GCI. However to make this operation feasible, preliminary treatments are needed. At first, climatic raw data measured at about 30 stations are redirected from the responsible Regional Agency server to our server. Data are processed according to the following steps:

1. *Retrieve.* At every event t in time, a secure file transfer protocol (SFTP) synchronization retrieves the current report of climatic data to be processed.
2. *Split.* This report is split to create a table for each climatic parameter;
3. *Decode.* Each record is placed in the database according to its climatic parameter and to its space–time position (i.e. precipitation at day t for station s);
4. *Check.* Time series checking to demarcate measured from missing and anomalous data. Anomalies are abnormal measured data and are detected by using a set of differently combined checks including logical, climatological, spatial, temporal and persistence checks.
5. *Infill.* Gaps due to missing and anomalous data – already flagged as missing – are infilled by using two (or more) competitive interpolation techniques: (i) a deterministic method (e.g. simple moving average with growing kernel and average value for that station and that Julian day), or (ii) statistical method (e.g. multilinear regression using data from other gauges after an optimization procedure).
6. *Map.* Spatial inference and delivery of digital maps. The output is a multitemporal stack of spatial maps of one or more required climatic parameter. The spatial inference is based on alternative/competitive methods from amongst inverse distance weighting, (multivariate) kriging, and a daily-adapted PRISM-like approach (Daly et al., 2008).

Each step represents a programming node, which can be turned on or off according to the kind of WeatherProg run that is performed. The most commonly used runs can process the daily records and produce the digital climatic maps for that day (the so called "daily call") or process past missing data that were not available before, for instance due to connection problems (the so called "integration call"). The result of performing a set of automatic runs of Weatherprog is the availability of a complete set of records for point stations and a complete temporal stack of digital maps of all the required climatic variables (such as minimum and maximum air temperature, precipitation, relative humidity, reference evapotranspiration and solar radiation).

Digital soil mapping
This engine – called cvSISE, Spatial Inference Selector Engine with Cross Validation – performs the spatial inference of pedological properties (Langella et al., 2012). The cvSISE engine was designed, implemented and deployed to support the routine query by users about the GCI which needs digital soil maps to be available to run attribute space inference systems and give an exhaustive web-integrated response. In order to accomplish this purpose, a set of models of spatial inference should be calibrated periodically (within one year intervals) to make up-to-date prediction maps. More specifically, at any scheduled time step, the cvSISE engine will only start if modifications of sample points and/or of covariates have occurred. Otherwise the most accurate digital map for any soil attribute which was accounted during the previous step is retained. This checking node enables the detection of new soil records or new/better defined auxiliary covariates and their automatic inclusion in the spatial modelling of soil properties. When a novel feature becomes available, cvSISEruns and calibrates different types of spatial models, each of which uses a jackknife leave-one-out cross validation procedure. Finally, the model making the least noisy proxy for the soil attribute of interest is selected to build the digital map. Different models of spatial interpolation are developed, including the representations given by the reference soil mapping units, inverse distance weighting, ordinary least squares regression and different kinds of kriging.

2nd level models

Among these are physically-based SPA hydrological models (Richards based), empirical hydrological models (bucket) and models to obtain bio-climatic indicators (e.g. Winkler).

Some of these models can be very complex and processing can be demanding. One of these cases is the SWAP model which is applied to find the soil water balance in the SPA continuum on a daily basis. In this case. the model belongs to the physically-based family. In the SOILCONSWEB-GCI, the model is applied in both “off-line” and “on-the-fly” mode (see later). SWAP is designed to simulate the Soil–Water–Atmosphere–Plant processes with a highly detailed structure for the soil–water module. It is actually a 1-D hydrologic model in which the soil water balances are based on the Richards’ equation (Kroes et al., 2006).

This model is usually applied after calibration procedures that require the monitoring of upper and lower boundary conditions (e.g. climate, water table depth) and soil water status (e.g. soil water content, soil pressure head). To run, it needs such data inputs as: (i) soil data (thickness, horizon sequences, physical and chemical characteristics, soil hydraulic properties, etc.), (ii) climate data with daily time step (rain, temperatures), (iii) plant data (roots depth, LAI, etc.), (iv) lower boundary conditions (e.g. dynamics of water table depth, impeding layer, etc.). In SOILCONSWEB-GCI, SWAP runs thanks to the georeferenced data input stored in the project database; this allows the application of the model throughout the study area.

As output, SWAP produces simulated data of soil/plant water balances with a daily time step. These dynamic data may be combined in order to obtain derived functional information or indices (i.e. water stress index). In some applications, the spatialized procedures developed for SOILCONSWEB-GCI enables the production of maps of the SWAP outputs.

3rd level models

Among these are models for the estimation of erosion (RUSLE); statistical models for the production of reports (mean, max, min, SD, etc.), empirical models to obtain indicators of urban planning (sprawl index), environmental, agricultural interests or more complex models such as those for spatiotemporal simulation of the risk of infection by *the Plasmopara viticola* grapevine fungus.

The complexity in the actual implementation of the modelling engines in the SOILCONSWEB GCI system varies enormously in accordance with the need to implement “on-the-fly” simulations and “what-if” modelling engines.

As shown in Table 3, all models employed into the SOILCONSWEB-GCI can be further classified into (i) models not enabling “on-the-fly” simulation and (ii) models enabling “on-the-fly” simulation. This classification is important because some models may be used with an off-line procedure; in this case pre-processing is required and the output is uploaded onto the server. This applies for many non-dynamic applications (e.g. maps of annual bioclimatic indices) or dynamic applications with a long time scale (e.g. maps of land use change over two years).

On the other hand, the need to deliver feedback to daily land and soil management and planning requires SOILCONSWEB-GCI to provide dynamic responses, for instance by taking into account the specific climatic conditions of the current crop year and, therefore, of daily, or even hourly, trends too. This requires the implementation of dynamic models, in other words models “must” operate in real time, so permitting “on-the-fly” processing over internet.

To make the modelling challenges even more complex, we must recall here that real life application in the field of agriculture and environment often requires the inclusion – for some models – of the so called “what-if” modelling engines. It is evident that the SOILCONSWEB-GCI system cannot include very local scale data/information in its platform, such as those dependent on a specific farmer’s management (crop of that year, fertilization, date of sowing, etc.).Thus, we had to develop models which enabled the user to apply his own parameters, which would then be used in model processing and produce output adapted to specific local conditions.

These “what-if” models implemented within the SOILCONSWEB-GCI system refer, for instance, to (i) the “soil water balance” under a specific crop, (ii) “protective capacity of the soil–crop system in terms of groundwater protection”, (iii) the “urban planning options” in terms of their impact on soil ecosystem services. In all these examples, it is essential that the end user inserts some local parameters (crop, sowing date, areas of new urbanization, etc.) in order to make the SOILCONSWEB-GCI models run properly.

Table 3 shows the main models employed by the SOILCONSWEB-GCI and where "on-the-fly" and "what-if" modelling engines were implemented. Models were tested and validated as part of different projects (e.g. Basile and Terribile, 2008; Manna et al., 2009; Bonfante et al., 2010). In most applications, basic statistics of the model output (e.g. means, min, max, SD) were produced by specific modelling engines.

3.1.3 Server services

The server provides a set of services (some examples are in Fig. 3-Services), which are implemented by using various technologies and standard formats for data exchange. These services achieve not only technical interoperability, but also contextual interoperability, as it mediates between the scripting environment and various client applications. In short, on the basis of dataset, models and modelling output, the system provides services which are accessed by users using various dashboards. These are the following (grouped in the services box in Fig. 3):

Map service: the implemented map services are the Web Map Service (WMS) and the Web Feature Service (WFS) both provided by an "instance of" Geoserver.

Model service: this is implemented with a mix of PHP scripts, C/C++/Fortran programs. PHP scripts oversee and control all the mechanisms for exchanging information between different modelling scripts (written in C/C++/Fortran), their operations and execution. They, also, format the responses and send the results to the client, following the standard interchange protocol.

Spatial statistic service: based on the same architecture as model service, this specializes in performing statistical calculations on multiple datasets, such as calculating means and variances in multiple layer stacks. The service summarizes the values of a raster within the zones of another dataset (either raster or vector) and presents the results as a table.

Reporting service: based on the server side PHP library “Fpdf”, which is expanded with an ad hoc code for data extraction and builds pdf documents from texts, tabular data and photos under program control.

3.1.4 Dashboards

Due to their nature of being the interface between the SOILCONSWEB-GCI and the end users, dashboards are a key component of the system and may eventually determine its success or failure. Hence, the planning, management and update of dashboards are an essential result of the system (Fig. 3-Dashboards). Moreover, dashboards must be perceived of as “very useful” to be successfully employed and, therefore, they must incorporate tools and processes that are chosen by end-users and which help them with their specific soil/land management problems.

On the other hand, dashboards should also be perceived of as “easy to use”. This was obtained by involving end users in dashboard planning and incorporating in the menu some items that may recall something that a user already knows (images, his farm, etc.). The design (and, therefore, attached functionalities) of these dashboards were the result of a series of interactions with communities of end users/stakeholders. Indeed, some users required the incorporation of complex system facilities such as the following:

Remote Internet GIS processing: e.g. to overcome administrative limitations in using GIS Desktop software (request by public offices of land planners at PTCP Benevento and forest managers at Regione Campania);

On-the-fly graphics: e.g. visual analysis of rainfall and temperature over the last few days in a freely selected area (request by viticulture experts and farmers);

On-the-fly simulations: e.g. Soil–Plant–Water stress evaluation to estimate the growing season (request by viticulture experts);

What-if algorithm: Evaluation of potential pollution by Nitrate towards groundwater (request by Regional offices dealing with nitrate directive).

Basically, regardless of the contexts, all dashboards allow land planning and land management through web-mapping applications, simulation modelling, spatial data reporting, data graphing, photos, etc. Basically, all of these features allow the user to access/explore/visualize both the existing spatial data (geology, soils, etc.) and new data (e.g. plant water stress) obtained by offline and online processing for the whole Valle Telesina landscape.

All dashboards have the same core and multiple adaptations in accordance with specific applications, so the user explores applications, on the basis of his needs, by activating sequential pop-ups which populate all of the dashboard components.

Figure 4 shows the general outline of the dashboard design. Fundamentally, all dashboards have a basic core made up of five different sections (red boxes in Fig. 4) and one section dealing with the required application. From right to left around the central display of Google map, there are (i) a *user area*: here all of the processing/information/data/graphs/maps/statistics requested by the user are recorded and activated upon new request, (ii) *WEBGIS facilities* which enable the user to navigate between spatial data layers (geology, soil, land use, etc.) for the whole Valle Telesina, (iii) *internet GIS facilities* which enable queries, map services and other requests to be made by the user as typically occurs in a desktop GIS (without any user need for a software license), (iv) *drawing/selection of the area of interest* (AOI), here the user can interact with the system by drawing his AOI or by selecting preexisting AOI (e.g. municipalities, land registry inventory ID, etc.), (v) *application dashboards*. This last section refers to the specific application chosen by the user and, therefore, it changes in accordance with the type of user.

During the login, the user is able to activate (click) all or just one of the applications according to his personal interests. In general terms, the Dashboard allows navigation that is adapted to multiple geographical levels and this reflects the need for the user to make decisions on different spatial scales.

The complex user interface of the presentation layer goes far beyond the concept of a lightweight client; it was developed writing lot of custom codes on the client side on the top of the huge frameworks used.

3.2 Applications of SOILCONSWEB GCI

The GCI system has two broad areas of application: Agriculture and Forestry and Environmental Protection (which include landscape and urban planning). Each of these two applications (and sub-applications) is explored through specific dashboards. Below, we provide a schematic description of these applications.

3.2.1 Agriculture and forestry (agriculture and forestry dashboard)

Agriculture and forestry applications allow multiscale, multidisciplinary, multi-stakeholder land planning and land management. The main architecture of the agriculture and forestry dashboard is given in Fig. 5. The user can either have full access to the whole dashboard or he can access just a specific application dashboard. Overall, there are the following 5 different applications/tools in the AOI:

- Description of main environmental factors (soil, climate, etc.);
- High quality viticulture;
- Olive growing;
- Land suitability for other crops;
- Forestry.

Most of these applications have two separate sections: planning and management. Here we provide a brief description of just one specific application, olive growing, in order to show how the system functions.

Application for olive growing

A scheme is reported in Fig. 5 which illustrates the hierarchical structure of the *Olive growing* tool. This includes many sub-tools in order to allow the end-user to (i) discover the main environmental features of the AOI and then (ii) obtain an environmental report (label) of the AOI, (iii) obtain specific mapping support for olive grove planning, (iv) obtain support for olive grove management. A composite figure is given in Fig. 6 showing how AOIs that have the same shape and surface (about 34 ha) can produce very different results in different parts of the landscape. On the left hand side, there is a series of outputs produced by the system in the "Olive Growth 1" area while, on the right hand side, the same type of results are reported for the "Olive Growth 2" AOI. The visual examination shows clear differences in terms of soil types, spatial variability of potential growing seasons and solar radiation. In the investigated period, min and max daily temperatures seem rather similar while daily rainfall shows moderate variation. In absolute terms, as reported in Table 4, the two areas show many other variations including altitude (200 m difference), annual rainfall (140 mm difference), geology (fluvial terraces as opposed to calcarenites and sandstones), soils with more eroded (Ustorthent) and less fertile soils in "Olive Growth 2" and, most interestingly for the specific application of olive growing, annual solar radiation (100 $\mathrm{kWh\,m^{-2}}$ difference) and potential water stress (3 % difference), as estimated by SPA modelling. Indeed, different varieties of olive tree can differ very much in terms of their water stress tolerance (e.g. *carolea* vs. *coratina* varieties) or in terms of the length of their growing season, as this is partially dependent upon insolation received.

3.2.2 Environmental protection (environmental dashboard)

Applications for environmental protection allow multidisciplinary, multi-stakeholder land planning and land management for a series of issues relevant to the Valle Telesina. In comparison with the Agriculture tool, the potential multiscale component of the system is less important here because of the specific type of user. To explain this issue, here we must highlight that In Italy the theme of environmental protection (with the exception of floods and landslides) is typically addressed by (i) one specific category of end-user, namely public regional bodies (e.g. Campania Region, River Basin Authority, Comunità Montana), and (ii) by analyzing rather coarse spatial scales (often from 1 : 50 000 to coarser). This is because they typically try to produce aggregated planning/management solutions.

A scheme of the internal architecture of the environmental protection dashboard is given in Fig. 7. For the above reason, the construction of a unique dashboard was required where the user could have full access to the whole dashboard. Overall, there are five different applications:

- Soil erosion (RUSLE based);
- Soil capability to protect groundwater from pollution;
- Disadvantaged areas;
- Soils and landslides;
- Sewage distribution.

In order to show the functioning of the system, we here provide a schematic description of the "soil protective capability towards groundwater pollution" application.

Application of soil capability to protect groundwater from pollution

A scheme is reported in Fig. 7 which illustrates the hierarchical structure of this tool named *Soil protective capability towards groundwater. The* tool includes an evaluation scheme for potential/actual estimates. Potential estimates refer to the intrinsic soil capacity to protect groundwater, calculated on a set of climatic years (climate for 30 years from 1961 to 1990 taken as reference, Basile and Terribile, 2008; Manna et al., 2009). while the actual estimate regards the opportunity given to the user to evaluate current protection capability by using current climate data and selecting the crop of interest.

In Fig. 8, we report a composite figure showing how AOIs with the same shape and extent (about 57 ha) can produce very different results in different parts of the landscape (main features in Table 4). On the left hand side, there are two outputs which were produced by the system in the "*groundwater protection 1*" area while, on the right hand side, the same type of results are reported for "*groundwater protection 2*". The visual examination shows clear differences in terms of their soils (the most important factor in differentiating results), while Table 4 reports the differences between the two areas in terms of both (i) potential soil protection capability towards groundwater pollution and (ii) actual soil protection capability towards groundwater pollution at a specific date and given a specific crop. In comparison with the other AOIs, the "*groundwater protection 2*" AOI has very different soil – namely a volcanic soil with vitric features (Ustivitrand) – and this in turn produces land which is much less able to protect groundwater. Here the soil protection class is only medium (as compared to the very high class of the other AOIs).

On the other hand, the actual soil protection capability – which considers the actual variation of soil water balance and daily climate – is the same for the two AOIs. This testifies to the fact that the large potential differences between the two areas do not show up when considering the specific climatic conditions during the period under consideration.

4 Discussion

In this paper, we have attempted to prove that geospatial cyber-infrastructure might be the way ahead for soil science applications, given the many diverse landscape issues. In fact, GCI can make the evidence of the central role that soil has in landscape planning and managing operational. In this way, the important, but sometimes vague concept of soil and landscape multifunctionality can become truly operational.

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In addition, SOILCONSWEB-GCI has shown the importance of embodying a multidisciplinary, multi-user, multiscale approach for the construction of a performing SDSS which is able to address the dynamic complexity of many current agricultural and environmental challenges.

In particular, the multi-user feature of the SOILCONSWEB-GCI is evident when navigating between the different types of users provided for by the system, while its multidisciplinary approach is based on the evidence that many of the applications in the fields of agriculture, forestry, land use planning and environmental protection require close integration between data/models of different natures (geology, soils, vegetation, climate, population, etc.).

The multiscale approach to SOILCONSWEB-GCI is also marked by the fact that some applications need to provide answers on a very local scale, as in the case of the "viticulture for high quality wine" application or that for forestry, while other applications, such as the one for "spatial planning", require answers on spatially more aggregate scales.

The example of the DEM applications can be useful to clarify further how data/models are complicated by the presence of different users and scales. In fact, in the SOILCONSWEB-CGI, the DEM data layer is used by a LiDAR technology, using an helicopter equipped with a laser scan. This takes place with a spatial resolution of 5 points m^{-2} if used for forest management or viticulture and with a spatial resolution of 20 m × 20 m if used as input parameter for determining soil erosion (RUSLE).

In any case, the system architecture has to be considered flexible and proactive. Indeed, it is designed to be open to further future implementations. Moreover, the system of dashboards for different applications shows that it is possible to combine many complex interactions between different contexts and processes within a single user-friendly and flexible interface.

We believe that the great effort involved in implementing SOILCONSWEB-GCI may be useful for future experiments and development of soil based SDSS. This motivates

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us to discuss some key points of this approach and some of the lessons learned. Amongst these, we cite the following:

(i) It is very important to have procedures which enable automatic or semiautomatic data acquisition, processing and recording of analytical data in the GCI. Indeed, in facing many current agriculture and environmental problems, these automatic systems are a “must”. For instance, without such automation, it would be impossible to give dynamic answers to support the daily management/planning of the rural landscape (which may depend, for example, on how much it rained yesterday) and it would be difficult to update – at a sustainable cost – databases (climate, soil, etc.). All this alleviates the need for constant updates and loading of datasets.

In this context, it would also be useful to be able to provide automatic data generation from very different platforms (remote sensing, data, web, etc.) within a single, robust and fully integrated, analytical infrastructure.

(ii) The contributions and feedback by end-users/stakeholders are fundamental for the development and management of dashboards. This activity, obtained through direct meetings, should also be made possible by means of flexible interactions via web which would facilitate continuous improvement of the system and interface.

(iii) User community: it is very important to widen as much as possible the group of potential users of these tools, and therefore their dashboards too. It would be helpful if some privileged categories of users could design their dashboards themselves.

(iv) Standard metadata: the project integrates information from many different disciplines. The integration of these data and their scalability requires a much larger effort than for those embedded in the actual specifications of International Standards for Data Exchange OCG. Indeed, these standards are certainly useful in the first phase of database exploration, but are not very useful for more detailed analysis or in integrating data from many different platforms, such as remote sensing, socio-economic, residential and hydrological data obtained from on the ground sensors, etc. In order to organize these GCI-based approaches, it would be very important

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to build/insert an engine capable of integrating different data and metadata, with an appropriate services catalog.

(v) Flexibility/interoperability: the existing infrastructure can be easily extended to include data/models from different sources (and in very different formats).

(vi) Integration of dashboards into the system of social media and mobile tools to disseminate the results and information better. These technologies offer great opportunities for the future, especially in developing countries where the use of smartphones is growing exponentially.

(vii) It is very interesting to note that, in the course of this 5 year project, there has been a rapid evolution in information technology (e.g. GPU processing) and software tools (open access Web-GIS). This has provided new opportunities for SOILCONWEB-GCI, such as the improvement of on-the-fly simulation modelling procedures. On the other hand, these developments have required computing engineers to be continuously active in adapting the system to new hardware platforms as well as in upgrading to new versions of operating systems. These updates are not always trouble-free and, in some cases, they can make the whole complex CGI platform risk collapse. Therefore, in this respect, the lesson is to duplicate the CGI platforms in order to have a 1st platform – not updated – but fully operational through the web and a 2nd platform – on which fully update (e.g. update of operating system, codes) and new developments are made. Only when the 2nd platform is considered stable can it replace the 1st platform and the two platforms can be switched.

5 Conclusions

Today's society increasingly requires access to information on critical issues such as agriculture, forestry, environment, urban planning, etc. The access to these data is obviously of primary importance, but if these data are included in an integrated SDSS-GCI (enabling geo-processing, simulation modelling, etc.), then it is indeed possible to support best decision/practices which lead towards the implementation of sustainable soil/landscape conservation and development. More specifically, we believe that this is the way to reconcile multifunctional landscape productivity with sustainable landscape management and conservation, while also considering climate change resilience and challenges.

In this respect, the SOILCONSWEB-CGI system – freely accessible through Internet browsers and embodying a dynamic SDSS system – has proved that this approach is feasible.

Here we demonstrated that it is possible to combine into a single system an ensemble of the following features: (i) user friendly (complexity is embedded), (ii) making the concept of soil/landscape multifunctionality operational, (iii) potentially adaptable to the needs of each end-user (action at local scale) and in terms of enabling the user to investigate his application regarding his own specific area of interest, (iv) enabling "what-if" modelling. The system does not always aim to provide best "solutions", but through modelling it can provide "options" for the user to choose from, (v) the openness and integration of the system encourages an increase in local communities' awareness of soil/landscape conservation/sustainable management issues, (vi) the system facilitates the incorporation of bottom-up contributions to governance.

An important issue to be raised here is the rather low cost of implementation (not considering data, calibration and validation) in new areas. In this respect, the SOILCONSWEB-CGI system – shown here simply for the Valle Telesina site – has actually been applied/tested (for specific modules) in 4 other areas (the Etna volcano area, southern Italy, for viticulture; Lodi plain, northern Italy, for soil sealing; Aversa plain, southern Italy, for groundwater protection; Wachau area, eastern Austria, for viticulture).

Despite the positive details given above, it is also necessary to emphasize that the construction/implementation of the infrastructure required a great effort in the following domains: (i) scientific effort to find the most suitable and robust approaches for each application/problem dealing with soil/landscape multifunctionality, (ii) scientific flexibility

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in that scientists often had to leave some of their approaches to developing new procedures/models to be adapted for web implementation and (iii) technical effort in order to make fully operational tools.

Some further considerations are necessary to evaluate future perspectives of these platforms.

It is very important to generalize the procedures/models implemented in the infrastructure as much as possible in order to simplify their application to new areas. Moreover, it is crucial to empower the prospects offered by bottom up contributions to governance. GCI must also embrace the opportunities offered by Web 2. and Web 3.0 in terms of their capacity for fruitful interaction and collaboration with users (social media, user generated content, virtual communities, etc.) as well as in terms of using semantic web opportunities (the web as a database). Thus, web-based social networks and users might act as potentially very effective collectors for a geo-referenced data provider of great value.

We also believe that the SDSS-GCI approach may represent a great opportunity both for soil scientists to demonstrate the central multifunctional role of soil in landscape planning/management and to provide operational (multidisciplinary, multitasking, multiscale) support to decision makers who have to live with and manage soil and landscape issues everyday.

However, all these strategies have a very high cost: scientists, technical assistants, landscape planners and managers, stakeholders and farmers must abandon some of their certainties and reschedule their work in terms of GCI implementation. Moreover – very importantly – a great effort is required from scientific communities to make GCI perform better in dealing with landscape multifunctional complexity and from scientific journals to guarantee the necessary discussion, scientific rigor and assessment when deciding between the different GCI approaches.

Here we must conclude by emphasizing that the system – developed with the help of end-users – is being adopted by local communities. What is more, the system – indirectly – is also exploring a change of paradigm for soil and landscape scientists.

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This shows that it is possible to overcome current disciplinary fragmentation over landscape issues and to offer – through a smart web based system – a truly integrated geospatial knowledge archive which can be used directly and freely by any end-user. This may help span the divide which, for years, has separated scientists working on the landscape from end-users.

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Table 1. Some important EU regulations concerning the management of agricultural/forestry and environmental issues. Abbr.: Dir.: Directive; Reg.: Regulation; Com.: communication.

EU Regulation/Directiv	List of the main objective	Required answe	
		in time	in space
Dir. 91/676 Nitrates Dir. 60/00 Water Framework	Land vulnerability towards nitrate pollution and adoption of the best management practices	Dynami	Varying across the landscape
COM 2006/231. Soil Thematic Strategy	State of soil threats as requested by STS.	Static/ Dynamic	Varying across the landscape
Dir. 60/00 Water Framework Dir.	Ameliorating water quality and quantity over river basins in terms of resilience to future climate change	Dynamic	Varying across the landscape
Dir. 2007/60 Flood Dir. Dir. 80/68/Groundwater against pollution	Evaluation of the soil protective ability towards groundwater pollution	Dynamic	Varying across the landscape
Dir. 86/276 Sewage sludge	Evaluation of the attitude and criteria for the application of sewage sludge	Static/ Dynamic	Varying across the landscape
Reg. (EC) 1782/031783/05 ACP System of conditionality	Farmer support to enter the system of conditionality	Dynamic	Varying across the landscape
Reg. 510/06 Reg. 1898/06 Designations of origin	Support for geographical indications and designations of food origin.	Static	Varying across the landscape
Reg. 1698/05 Reg. 1974/06. Rural development in forestland	Best practices in order to achieve good forest maintenance	Dynamic	Varying across the landscape

Table 2. Main databases employed in SOILCONSWEB-GCI: description of data type and examples of their use/importance in modelling.

Theme	Data: category and description			Data used in modelling		
	Source database and (spatial/time) resolution	Type of file	Data	Parameters (obtained by dataset)	Applied model	Example of model outputs
Administrative units	Municipalities, Macro-area; other bodies (Mountain administrative offices, etc.)	Polygon	Administrative boundaries	Area of municipality	Urban sprawl, urban statistics	Rural integrity, urban environment statistic report
Legal restriction to land use	Natura 2000; Hydrogeology restriction	Polygon	Legal boundaries	Limit and type of restriction	Presence/absence of restriction	Surfaces under restriction
DEM	20 × 20 (contour level); 5 × 5 (resampled LIDAR);	Grid	Mean height	Spatial coordinates and height	Fuzzy landform segmentation	Estimate of soil erosion
Agro-meteorology	Raw data from weather stations of the Regional meteorological network; daily and hourly data; 1 station per 2000 ha	Point	Checked data on rainfall, temperature, rel. humidity, etc.	Cumulative rainfall, max/min/average temperature, cumulative evapotranspiration, etc.	SPA modelling	Soil hydrological properties (water content/storage, etc.)
	WeatherProg internal database (checked time-series at gauged locations); daily and hourly data; 1 station per 2000 ha	Grid	Digital climate maps of rainfall, temperature, etc.	Cumulative rainfall, max/min/average temperature, cumulative evapotranspiration, etc.	SPA modelling	Soil hydrological properties (water content/storage, etc.)
Geology	Geological map/1 : 100 000 Geomorphological map/1 : 50 000	Polygon	Geological units Geomorphological units	Description of setting	None	Landscape awareness Viticulture zoning
	Hydrogeology map/1 : 250 000		Hydrogeology units	Lower boundary settings for modelling	Water balance modelling	Water storage and water fluxes in the HCZ
Soil	Soil mapping databases/1 : 50 000	Polygon	Main soil morphological, chemical, physical parameters, STU	SOM, clay content, soil depth	SPA modelling	Quantification of soil ecosystem services and land suitability maps
	Soil survey campaign		Soil hydrology parameters	Water retention curves, Hydraulic conductivity curves	SPA modelling	Soil water balances and storage
			Soil fauna classification	Soil biodiversity indexes	None	Maps of soil biodiversity
Land use	Corine Land use map/1 : 50 000 (1954 TCI, 2001 Campania region, 2011 new survey using remote sensing)	Polygon	Land use mapping units	Description of setting	Erosion (RUSLE)	Estimate of soil erosion Landscape awareness
Forestry	Forestry map (1 : 5000)	Polygon	Forest map units	Description of setting	None	Maps of forest types
	LIDAR/5 points m^{-2} (calibrated with field measurements)	Grid	Map of 5 echoes	Height of stands	C stock; Growing stock; above ground biomass	Maps of quantified stands parameters

Table 3. Modelling details in SOILCONSWEB-GCI.

Modelling chain	Theme of Model	Model	Main functionalities	Availability of source codes	Required activity to implement in SOILCONSWEB	Examples of input parameters	Examples of output in the S-DSS	On-the-fly simulation	What-if model
1st level	Zonal statistics	General model used in open GIS environment	statistic in each zone dataset based on values from another dataset	Y	direct implementation of functions	Any raster variable	Reporting of the area of interest	Y	
	Climate	WeatherProg (gauged data is: retrieved, decoded, checked, infilled and mapped)	Several Agriculture and Environment applications	NA	writing new codes	Raw data from weather stations	Checked and harmonized time series at gauged locations; Digital climate maps	Y	
		Selecting centroids in drawn areas	Climate trends	NA	writing new codes	Spatialized weather data	Graphs of climate trends (i.e rain, temperatures)	Y	
		Combining raster dataset	Bio-climatic indicators	NA	writing new codes	Spatialized weather data (including climate change scenario)	Maps of bio-climatic indicators (i.e. Winkler index, Branas index, etc.)	Y	Y
	Soil	cvSISE (Spatial Inference Selector Engine with cross validation)	spatial inference of pedological properties	NA	writing new codes	Measurements of pedological properties at soil survey locations (e.g. clay content or organic matter)	Digital soil maps of specific pedological properties at the required level of pedological support	Y	
2nd level	Water balance	Combining raster dataset	Evapotranspiration	Y	writing new codes	Spatialized temperature data	Graph of Potential Evapotranspiration vs. time	Y	
		Interactive real-time SWAP	Soil water content	Y	Adapting the codes	Plant parameters, data from soil and climate database	Vector and tabled data of actual soil water content	Y	Y
		Off line SWAP	Loss of soil hydrological functions	NA	Direct implementation	Plant parameters, data from soil and climate database (including climate change scenario)	Tabled data related to the loss of soil capacity in groundwater recharging		Y

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Soil based spatial decision support system

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Table 3. Continued.

Modelling chain	Theme of Model	Model	Main functionalities	Availability of source codes	Required activity to implement in SOILCONSWEB	Examples of input parameters	Examples of output in the S-DSS	On-the-fly simulation	What-if model
3rd level	Land management	Interactive real-time RUSLE	Rate of soil erosion	NA	Direct implementation	Land cover type, data from soil database, type of anti-erosion management	Raster mapping of potential and interactive soil erosion	Y	Y
		Interactive real-time SWAP	Soil protective capacity	Y	New compilation under UNIY after modification of FORTRAN source code	Plant parameters, data from soil and climate database	Vector mapping of interactive soil protective capacity	Y	Y
		Matching dataset	Land use change matrices	NA	writing new codes	Raster and vector data related to land use at different times	Tabled data and statistics relating to land use change over time		
			Soil sealing	NA	writing new codes	Raster and vector data related to soil sealing at different time	Tabled data, statistics and maps related to soil sealing evolution over time		
		Item counts in areas with variable extent	Landscape fragmentation	NA	writing new codes	Raster and vector data related to soil sealing	Raster maps of rural fragmentation and indicators of urban interest	Y	Y
	Agricultural management	Empirical model based on climate data	Trends of quality parameters	NA	writing new codes	Spatial climate data (temperatures)	Graphs of quality parameters values (i.e. briY degree, acidity)	Y	Y
		Interactive real-time SWAP	Supplementary irrigation based on soil–plant water stress	Y	New compilation under UNIY after modification of FORTRAN source code	Plant parameters, data from soil and climate database	Graphs of plant water stress values provisions (i.e. vine)	Y	Y
		Simplified Plasmopara viticola model (Rossi et al., 2008)	Spatiotemporal plant pathogen simulation	Y	Writing new codes	Digital climate maps (temperature, rainfall, relative humidity)	Graphs of the risk level of infection by grapevine Downy mildew		
	Data reporting	Models constructing reports	Statistical and informative reports	NA	writing new codes	Potentially all data stored in the project database	Downloadable reports and table (.PDF, .Yls, .tYt)	Y	

Table 4. Detailed spatial information about Figs. 6 (Olive growing) and 8 (Groundwater protection).

Site		Olive growth 1	Olive growth 2	Groundwater protection 1	Groundwater protection 2
Surface area [ha]		34.1	34.1	56.6	56.6
Municipality		Guardia Sanframondi (BN)	San Lorenzo Maggiore (BN)	TeleseTerme (BN)	San Salvatore Telesino (BN)
Coordinates of the centre of the area		41°13′49″ N 14°36′01″ E	41°14′48″ N 14°36′55″ E	41°12′18″ N 14°30′50″ E	41°12′57″ N 14°29′43″ E
Elevation (average) [m a.s.l.]		118	318	43	76
Slope (average)		15 %	26 %	2 %	2 %
Aspect (average)		West (258)	West (277)	South (173)	South (179)
Annual rainfall [mm]		1600.0	1460.0	1370	1270
Annual Temperature °C	mean	14.9	15.1	15.8	15.7
	min	−7.3	−7.4	−6.8	−6.9
	max	39.2	39.3	39.8	39.6
Rain (last recorded event) [mm]		0.0	0.0	0.0	0.0
Temperature (last recorded event) °C	mean	14.3	13.5	14.8	14.6
	min	0.0	0.0	0.0	0.0
	max	28.6	27.0	29.5	29.1
Geology		Sands and gravel of fluvial terraces: 33.7 [ha] (98.7 %)	(i) Calcarenites: 23.0 [ha] (67.5 %); (ii) ClayeySandstones 11.1 [ha] (32.4 %)	Sands and gravel of alluvial plain: 56.6 [ha] (100 %)	(i) Sands and gravel of fluvial terraces: 43.7 [ha] (77.3 %); (ii) Ignimbrites: 12.9 [ha] (22.8 %)
Legal restrictions		None	None	Site of Community Interest: 28.1[ha] 49.7 %	None
Land Use 2011		(i) Olive trees: 17.7 [ha] (51.8 %); (ii) Vineyards: 8.4 [ha] (24.5 %); (iii) Vineyards consociated with other crops: 7.5 [ha] (21.9 %)	(i) Olive trees: 13.6 [ha] (39.9 %); (ii) Vineyards: 9.8 [ha] (28.9 %); (iii) Vineyards and other crops: 4.0 [ha] 11.8 %; (iv) Mixed forest (broadleaves): 3.1 [ha] 9.1 %; (v) Rainfed crops: 2.3 [ha] 6.7 %	(i) Vineyards: 28.3 [ha] (49.9 %); (ii) Bushes and shrubs: 9.6 [ha] (16.9 %); (iii) Rocky outcrops: 7.5 [ha] (13.2 %); (iv) arable crops and forage: 4.4 [ha] (7.8 %)	(i) Vineyards: 45.2 [ha] (79.9 %); (ii) Industrial area: 4.0 [ha] (7.1 %)
Soils		Association of (i) Typic Haplustolls (La Cerasa): 17.7 [ha] (52.0 %) and (ii) Typic Haplustepts (Codacco): 13.2 [ha] (38.8 %); Consociation Typic Calciustolls (TavernaSt.): 3.1 [ha] (9.1 %)	Association of (i) TypicCalciustolls (Petrara): 20.2 [ha] 59.3 % and (ii) TypicUstorthents (Cese): 13.2 [ha] 38.7 %	Association of (i) Typic Ustifluvents (Calore): 31.5 [ha] 55.7 % and (ii) Fluventic Haplustepts (Ponte Cav.): 15.7 [ha] 27.8 %; (iii) Fluventic Haplustepts (s. la Ripa): 6.4 [ha] 11.3 %; (iv) Typic Vitraquands (P. del Lago): 3.0 [ha] 5.3 %	Consociation of Humic Ustivitrands (Sperazzo): 56.6 [ha] 100. %
Annual solar radiation [$\mathrm{kWh\,m^{-2}}$]	mean	1140	1240	1120	1130
	min	991	1130	1080	1090
	max	1230	1310	1150	1160
		1114 – mean of whole Telesina valley			
Water stress [%]	mean	20	17	21	12
	min	19	15	15	12
	max	21	20	21	12
		15 – mean of whole Telesina valley			
Potential protective capability towards groundwater pollution	Index	NA	59	46	
	CV	NA	13	19	
	Class	NA	very high	medium	
Actual protective capability towards groundwater pollution	Index	NA	61	61	
	class	NA	very high	very high	

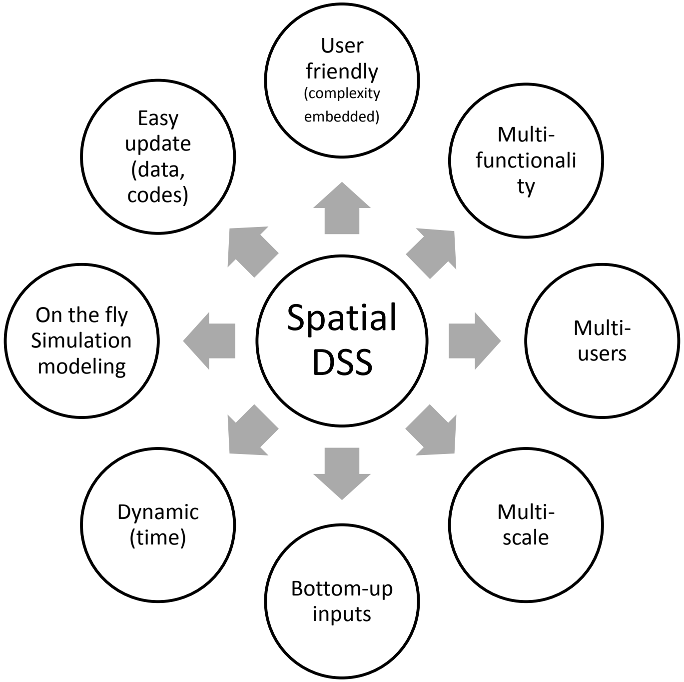

Figure 1. Features to be expected of a Spatial-DSS system in order to address current complexity of agriculture and environmental challenges.

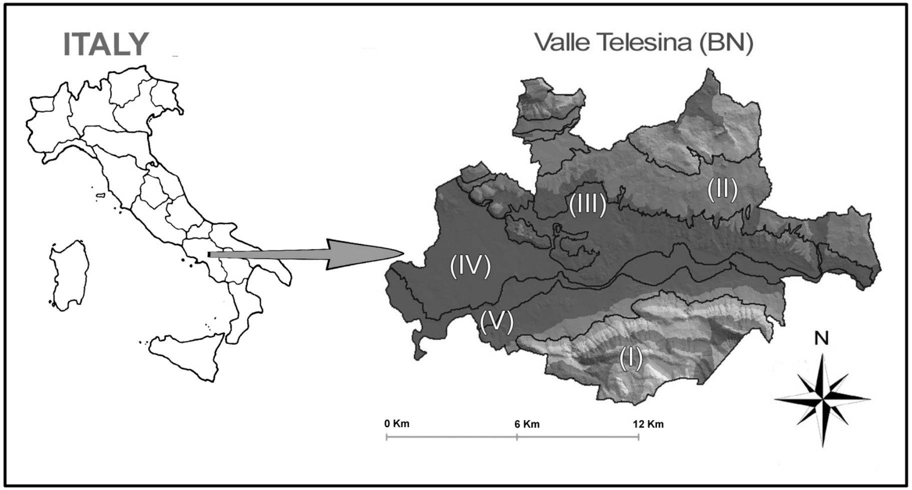

Figure 2. DEM of Valle Telesina and the main landscape systems: (I) mountains, (II) hills, (III) pediment plain, (IV) ancient fluvial terraces, (V) alluvial plain.

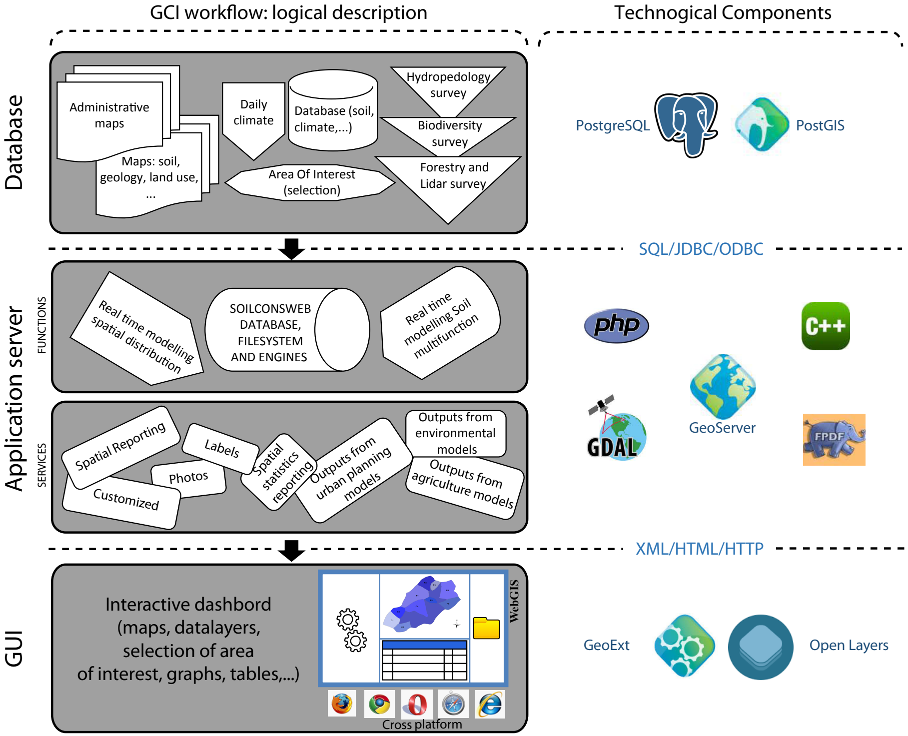

Figure 3. Simplified diagram describing SOILCONSWEB geospatial cyberinfrastructure architecture and its main technological components. Abbrev. GUI: graphical user interface.

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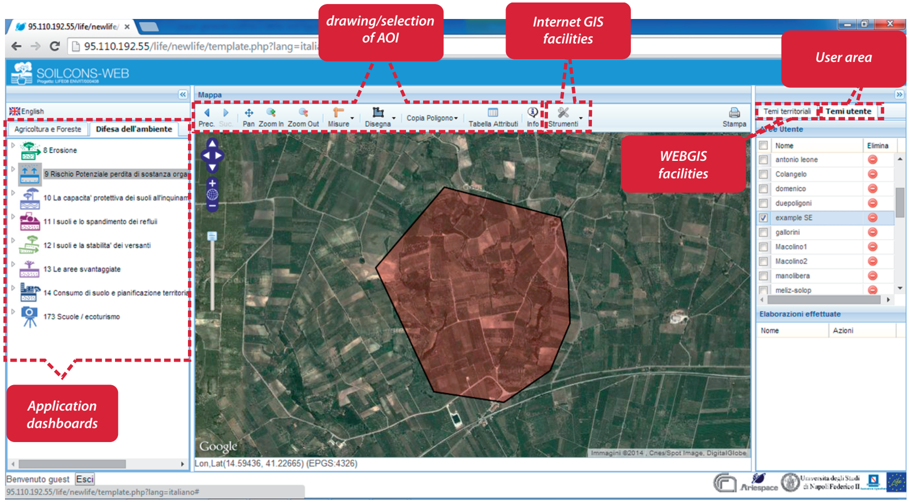

Figure 4. Dashboard design. The user can navigate – in accordance with his needs – by using the 5 different sections (in red). The individual dashboard tools are written in Italian since the system is, for the moment, aimed to local Italian communities of users.

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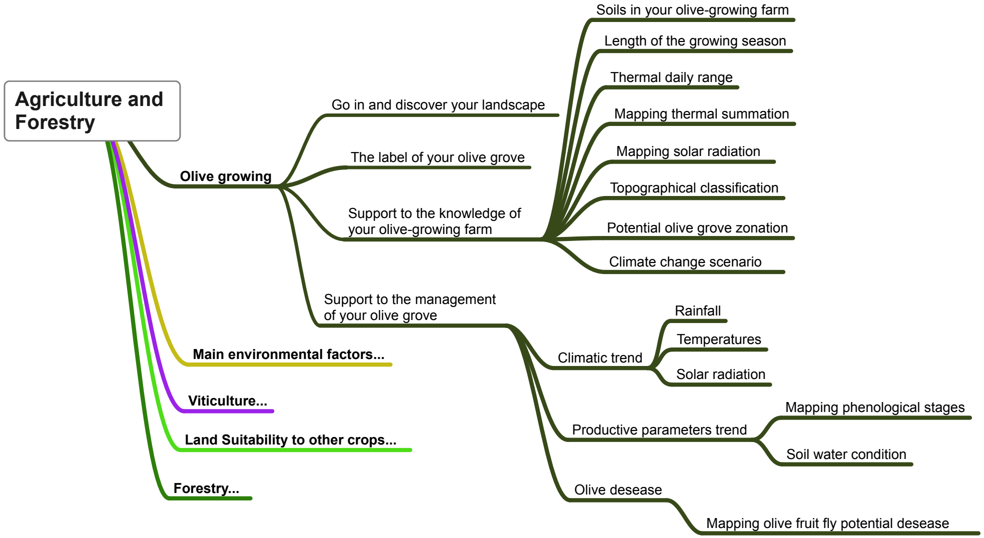

Figure 5. Conceptual map illustrating the main themes of the agriculture and forestry dashboard; the *Olive growing* dashboard is presented as an example.

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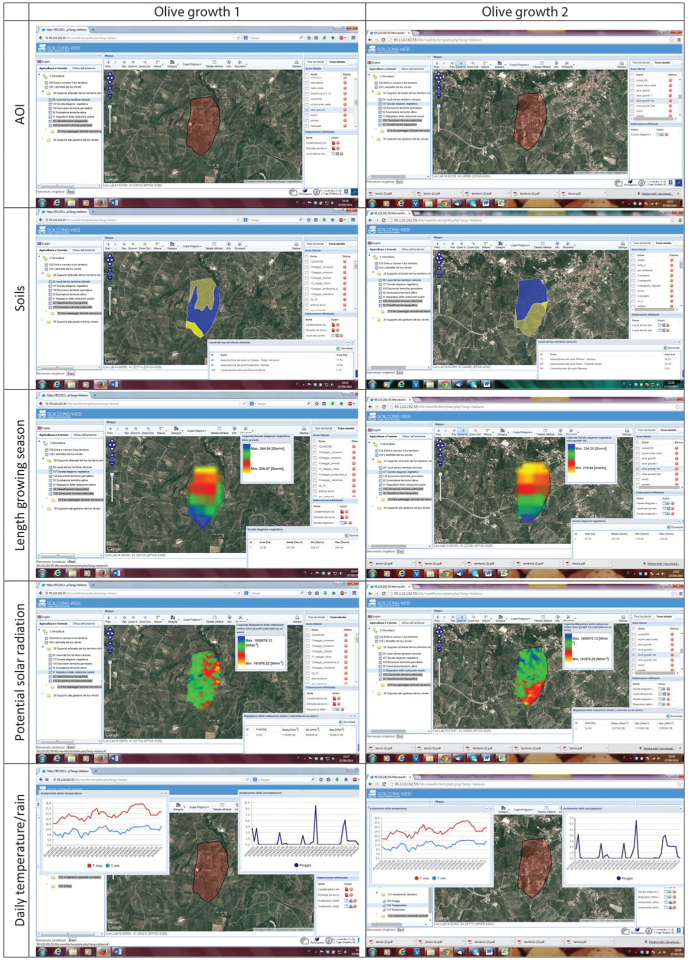

Figure 6. Output examples from the support for "*Olive growth*" tool.

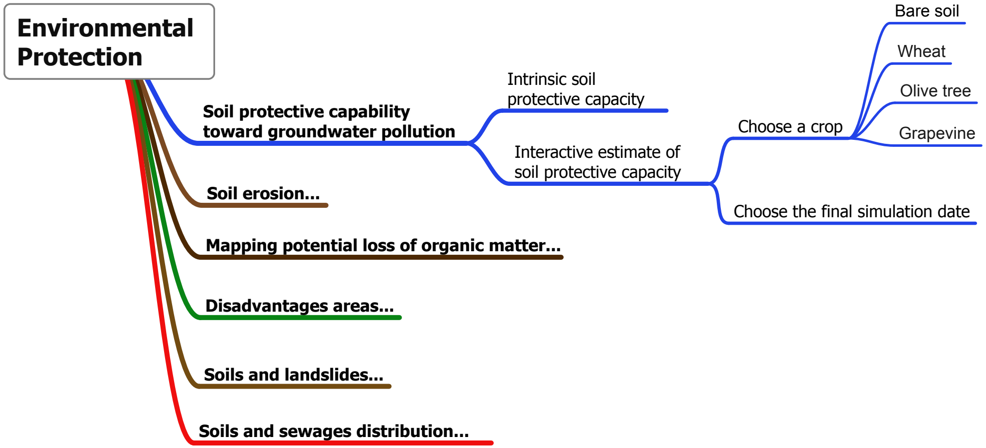

Figure 7. Conceptual map illustrating the main themes of the Environmental protection dashboard; the *Soil protection towards groundwater pollution* dashboard is given as an example.

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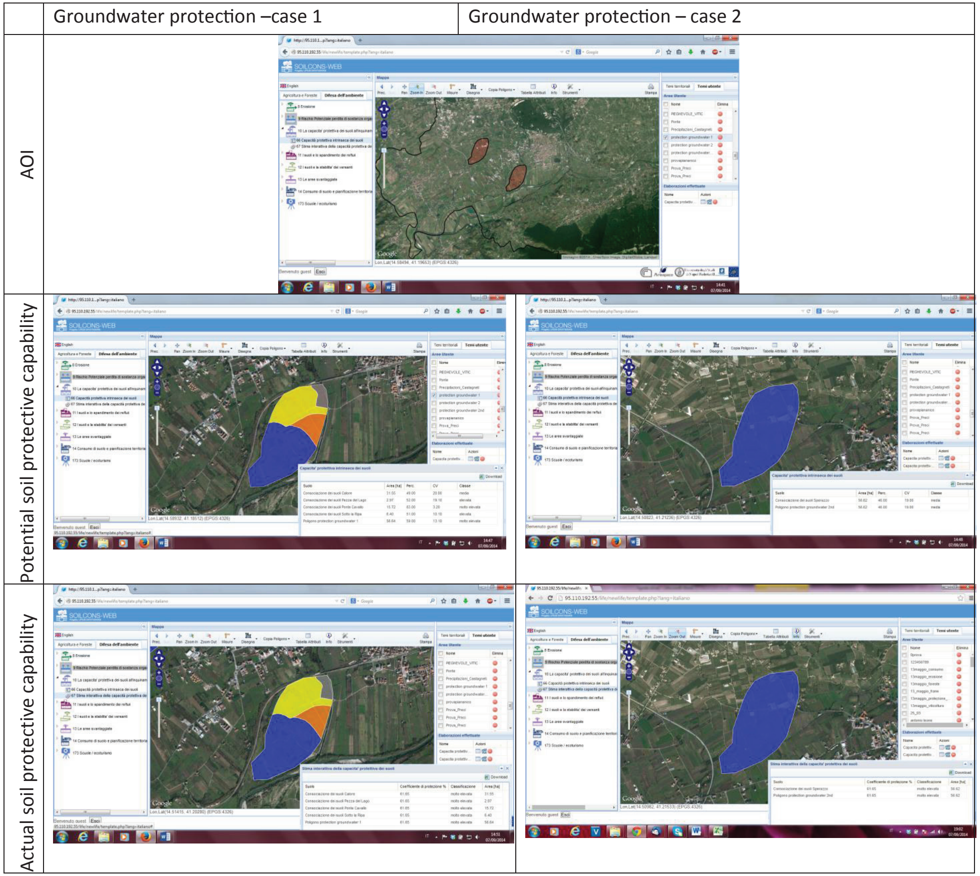

Figure 8. Output examples from the "*Soil protective capability towards groundwater pollution*" tool.