

A geospatial decision support system to assist olive growing at the landscape scale



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ABSTRACT

Olive cultivation is a very important activity which performs several important ecological functions in many inland areas.

Recent progress in modelling and Decision Support Systems (DSS) applied to agriculture promises to deliver important positive changes. However, most of this progress regards agriculture systems other than olive growing, so failing to challenge the environmental dimension of the olive grove and the landscape, which is a key issue in the planning and management of olive cultivation.

This paper aims to demonstrate that a new type of DSS developed upon the open-source Geospatial Cyberinfrastructure (GCI) platform (named GeOlive) can provide a very important web-based operational tool for olive growing as it better connects productivity and environmental sustainability.

This GCI platform supports the acquisition, management, and processing of both static and dynamic data (e.g. pedology, daily climate), data visualization, and computer on-the-fly applications in order to perform simulation modelling (e.g. evaluation of bioclimatic indices), all potentially accessible via the Web.

The DSS tool, applied to an area of 20,000 ha in southern Italy, is designed to assist olive grove planning and management and provide operational support for farmers, farmer associations and decision makers involved in olive grove landscape.

DSS outputs include olive grove planning and management scenario analysis and maps, together with evaluation of potential and current plant water stress.

A short selection of practical case studies is presented to show the different use cases of the proposed DSS.

1. Introduction

Olive cultivation worldwide occupies about 11 million ha; the Mediterranean is the most intensively cultivated olive growing area and constitutes more than 90% of the world total. In few European countries olive cultivation is more than a crop system since it has very important ecological and hydrogeological functions along with crucial historical, cultural services and thus positive consequences on the tourism, the rural economy and environmental services (Cecchini et al., 2019; Cohen et al., 2015).

This multifunctional role requires appropriate support in order to attain the planning and management of sustainable high-quality olive

cultivation. This paper describes an approach to support high-quality olive cultivation, the work below is organised as follows: after the introduction, Section 2 discusses related work, Section 3 presents the development of GeOlive tool, Section 4 shows some use cases of the tool, and finally, Section 5 has discussion and conclusions.

2. Related work

In recent years, the scientific community has made many contributions to better olive grove management and planning by applying/developing models, mapping procedures and also DSSs (Decision Support Systems). Among those: (i) field scale new management and

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sustainable approaches (La Scalia et al., 2016; Russo et al., 2015; Caruso et al., 2014), (ii) pest management by webGIS application, DSS and olive fly modelling (Zaza et al., 2018; Doitsidis et al., 2017; Pontikakos et al., 2012). Many of these approaches are based on modelling; models applied to olive grove are typically classified as either empirical/statistical or dynamic. Empirical models are based on statistical relationships between environmental parameters (e.g. multiple regressions), are generally intuitive and well accepted. They include those based on climate data (Zaza et al., 2018; Iglesias et al., 2010), those based on remotely sensed indices (Blum et al., 2013, 2015) and those based on multicriteria analysis (Carmona-Torres et al., 2014). Although highly used, these models have various weak points, such as the high degree of calibration required (when applied to a new environment) and – most importantly – the fact that they do not address the non-linear relationships between factors involved in the cultivation systems (e.g. soil-plant-climate continuum). On the other hand, dynamic models attempt to solve these non-linear relationships varying over time, thus allowing greater generalization of the processes involved (e.g. crop growth, biomass accumulation, seasonal hydrological requirements, etc.) and, consequently, better adaptation to new environments and much better overall performance. The coupling of these models with the simulation of climate scenarios has also allowed progress to be made in predicting the adaptation of olive trees, and crops in general, to future climatic conditions (Ropero et al., 2019; Fraga et al., 2019; Alfieri et al., 2019; Morales et al., 2016).

In this view, a crop-modelling coupled with DSS is a useful tool that provides growers and decision makers with reliable information on crop status during current and future seasons.

Unfortunately, it is important to stress that the majority of these olive grove models when integrated into operational DSSs architectures, refer to the only pest control (Zaza et al., 2018; Doitsidis et al., 2017; Pontikakos et al., 2012), operate at farm level and are marketed as commercial services. Moreover, while fully recognizing the great importance of the described approaches, it is also important to highlight that these systems do not adapt easily to territorial complexity and its space-time variability. These issues could be considered the key points on the base of which our approaches in developing DSSs differ from the others.

In fact olive grove planning and management require to address many environmental elements of the olive growing systems, including spatial and temporal variability of climate, landscape morphology, soils, land use and land cover, etc., while the specialized DSS systems reported above typically consider the farm as an individual point in space or, for very large olive growing farms, “a small set” of individual points (Zaza et al., 2018; Karydis, 2013; Alamo et al., 2012; Orellana et al., 2011).

In this respect, recent progress in dynamic modelling and its implementation in spatial DSSs (S-DSS) (Manna et al. 2017, Terribile et al. 2017, Langella et al., 2017, Bonfante et al., 2019) may also promise interesting developments for olive grove applications which integrate field to territorial scales.

Moreover, it is also clear that high-quality olive cultivation is nowadays asked to provide multifunctional outcomes including ecosystem services (e.g. hydrological functions, biodiversity, etc.) and even support for ecotourism (e.g. monumental trees, cultural heritage, etc.). This multifunctionality needs to be developed into a coherent landscape framework rather than operating at isolated farm level.

3. Aim

Therefore, we assert here that when dealing with high quality olive grove planning and management there is, somehow, a disconnection between the large, important research advances performed in the field of plant and pest modelling and the need for a broader multifunctional approach.

We believe that this gap can be filled with the development of

operational spatial DSS tools for multiusers (from individual farmers to olive growing associations and public bodies) which address processes variable over time and the complexity of the physical landscape in the olive cultivation framework. In the light of the above considerations, the general aim of this paper is to demonstrate that a new type of spatial DSS developed upon Geospatial Cyberinfrastructure (GCI) platforms can provide a very important web-based operational tool to challenge multifunctional olive growing from farm to landscape scale.

Here, we describe a Web tool developed as a component of a more general multipurpose Geospatial Decision Support System (S-DSS) named SOILCONSWEB, currently in use (www.landconsultingweb.eu) and described in its general framework in Terribile et al., 2015. The specific tool described here and named GeOlive – is applied to an area of 20,000 ha (South Italy) and is designed to assist sustainable olive cultivation planning and management by providing operational support for farmers, farmer associations and decision makers. GeOlive is currently under further new development (e.g. larger scales of applications, new modelling approaches, new codes solutions, etc.) within the Horizon 2020 LANDSUPPORT research (www.landsupport.eu).

Below we report the framework development and the main components of the DSS tool. Some applicative “case of use” will be described (full details are given in the [supplementary materials](#)) to highlight the GeOlive potential to aid practical decision making.

4. GeOlive development

4.1. The Geospatial cyber-infrastructure

SOILCONSWEB belongs to the family of Geospatial Cyber-Infrastructures (GCI) which make use of free open-source geospatial libraries and programs. GCI platforms (Yang and Raskin, 2010) can support acquisition, storage, management and integration of both static (e.g. pedology, geology) and dynamic data (e.g. daily climate, spatial distribution of olive cultivation within an area), data visualization, and computer on-the-fly applications (such as those enabling simulation modelling for determining plant water stress). Through the platform, users are able to interact with digital maps and geospatial data directly via web, in real time or quasi-real time.

Basically, SOILCONSWEB has a 3-tier structure in which data management, data processing for the applications and data presentation are separate processes. The management process involves a geo-database in which the information (e.g. vector and raster georeferenced data, climate data, etc.) are stored and retrieved when needed. The processing data tier checks the application’s functionality, while the presentation tier is the tool thanks to which the information from processing services is displayed for users. This client-server communication is based on AJAX (Asynchronous JavaScript and XML) technology and most of the data are transferred into JSON format. Graphs and maps are presented in the Graphical User Interface (GUI) by using YAHOO Charts as a part of the ExtJS library.

In Fig. 1, a scheme of the platform framework is shown which can be accessed by the GUI.

Here it is important to emphasize that the use of these technologies indeed requires that the user is willing and/or able to use computers and web navigation. We have performed a preliminary estimate (see [supplementary materials](#) for details) on the potential propensity of farmers to use both computers and web navigation by analyzing the available socioeconomic databases for the olive sector in the studied area. The following sections will describe in detail the 3-tier structure of the system (Fig. 1) and the modelling application.

4.2. The geo-database

The dataset stored in the geo-database and connected to the olive growing GCI Web tool includes geo-referenced data and metadata from different sources (Table 1). The main types of data include: (i) thematic

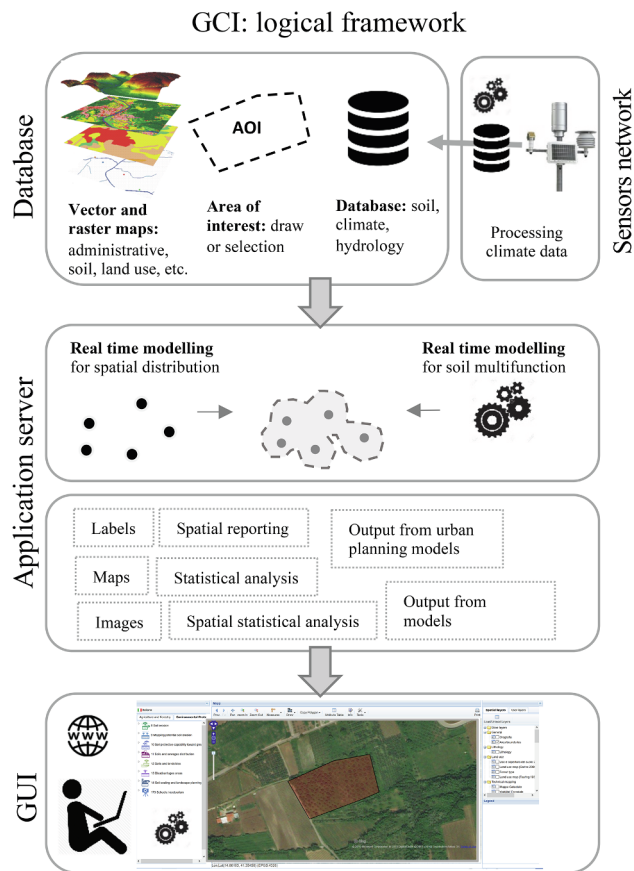


Fig. 1. Geospatial Cyber-Infrastructure operating mode. The flow of data feeds different server functions, which in turn produce a set of services that can be accessed by the dashboard. Abbr. GUI: Graphical User Interface.

maps in the form of polygon or grid data as soil and geological maps, land use maps, bioclimatic and biodiversity index maps, and maps of protected sites; (ii) basic physical data (e.g. the LiDAR high-resolution digital elevation model); (iii) data from specific field survey activities (e.g. soil hydrology, chemical and physical properties); (iii) simulation modelling (e.g. soil water balances). Before being integrated into the database, all of the data checked for anomalies and subjected to up-scaling procedures if required (i.e. lower resolution data for specific applications). Land use maps with different code classes (e.g. Touring 1954 and Land Use Land Cover Map LULC 2017 edited by the Italian National Institute for Environmental Protection and Research) were harmonized in order to be comparable and applicable within a tool for land use change analysis over time. A detailed description of the management system of the geo-database is reported in [Terribile et al., 2015](#).

4.3. Models: Basic procedures

The GeOlive tool aims to support olive growing planning and management at the territorial scale. This task involves issues at different levels of complexity and, subsequently, the models implemented are also more or less complex in accordance with the type of issues to be faced. This is why, in some cases, these models can be simple (e.g. based on empirical data) or complex (e.g. mechanistic processes such as soil water flow in the soil-plant-atmosphere system, SPA). Sometimes models may also be implemented with a modular framework (e.g. modelling cluster) enabling operative interaction in which the output of a model constitutes the input for a second one.

There are a few important modules to be reported here that are fundamental for the GeOlive application described in this work: (i) a

module that uses a recoded version of the original SWAP model ([Kroes et al., 2008](#)) for Linux to perform simulations on water balance in the SPA. SWAP has already been successfully used in our study site (described later) by [Alfieri et al. \(2019\)](#) and [Bonfante et al. \(2010, 2011, 2018\)](#), who also calibrated and validated the model; (ii) an engine for both the automatic processing of climate data and the production of digital climate maps ([Langella, 2014](#); [Langella et al., 2016](#)). See [supplementary materials](#) for details; and (iii) additional algorithms such as those based on digital terrain analysis ([Wilson and Gallant, 2000](#)). A detailed description of these modules is reported in [Terribile et al., 2015 and 2017](#).

4.4. The Graphical user Interface (GUI)

Fig. 2 shows the general outline of the Graphical User Interface (GUI) developed for the GeOlive tool. The GUI is made up of five different sections (dashed line boxes in Fig. 2). From right to left on the central map display, there are (i) a user area in which user queries are recorded, (ii) webGIS features which enable the user to navigate through spatial data layers, ask questions, evaluate spatial statistics by matching several layers (vector and raster) and make other requests, (iii) drawing/selection of the area of interest (AOI), and (iv) dashboards for the Geospatial olive grove GeOlive tool. The latter has many models and routines to answer the several questions posed by end-users. This application dashboard has its own hierarchical structure (Fig. 2 left side) with three main categories, (chosen on the basis of interaction with stakeholders) to separate the main domain of olive grower's interest:

- o General description of the AOI: it includes applications for the description of the area chosen by the end user. Basically, the user gets a report (real time automatically made .pdf file) describing the main geological, climate, soil and land use features of his AOI.
- o Planning: this set of tools is aimed at olive cultivation planning within the AOI. It includes tools built to produce reports, maps and statistics regarding the AOI on the spatial distribution of soils, bioclimatic index, potential plant adaptability to climatic conditions, potential solar radiation, etc.
- o Management: these tools provide support for management practices. In GeOlive, they currently include climate monitoring. The user can obtain graphs and table data relating to daily temperatures and rainfall, both for the area of interest and for selected time windows, to be used as support data in pest management for example.

4.5. Modelling

All the applications described have in common the possibility to process geospatial data referred to as user defined AOI. Indeed, several processing procedures run behind these tools, ranging from simple visualization of thematic maps to more complex elaborations by applying dynamic simulation models. The latter are essential if GeOlive is to address agronomic issues deeply connected with the functionality of the SPA system such as the water balance, governed by processes varying in time and space.

A schematic description of models implemented in GeOlive is provided in [table 2](#). These can be described according to: (i) their functions; (ii) activities required for their implementation; (iii) required input parameters; (iv) main outputs; and (v) capacity to enable the "on the fly" operations. The last point is very important to distinguish models running in real time from those whose functionalities are exploited off-line.

Indeed, some models may be used with an off-line procedure and the output produced is uploaded onto the server, ready to be used for other modelling applications or to be directly visualized (e.g. maps, tables etc.). Below are two examples of these off-line procedures:

The use of bioclimatic indices which can be used to address

Table 1
(Adapted from [Terribile et al., 2017](#)). Main databases employed in SOILCONSWEB-GCI for the GeOlive tool: description of data type and examples of their use/importance in modelling.

Data: category and description		Data used in GeOlive tool			Applied model	Example of model outputs. Collection of:
Theme	Source database and (spatial/time) resolution	Type of file	Data	Parameters (obtained by dataset)		
Administrative units	Municipalities	Polygon	Administrative boundaries	Area of municipality	Clipping spatial data from database	Environmental data within administrative boundaries
Legal restriction to land use	e.g. 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	Elevation pixel based	Spatial coordinates, elevation, aspect, slope	Clipping spatial data from database; zonal statistics	Geomorphological data within the AOI
Geology	Geological map / 1:100,000 Geomorphological map /1:50,000	Polygon	Geological units Geomorphological units	Data description of geological and geomorphological units	Clipping spatial data from database	Geomorphological data within the AOI
Soil and climate	Hydrogeology map / 1:250,000 Soil mapping databases/ 1:50,000	Polygon	Main soil morphological, chemical, physical parameters	Lower boundary settings for modelling Soil organic matter content, texture data, soil depth, classification and physical parameters	SPA modelling Clipping spatial data from database; zonal statistics; process-based SPA modelling	Water balances: soil water content, etc. Soil data within the AOI; Water balances according to land use Olive growing: Evapotranspiration stress index, etc.
Bioclimate	Raw data from weather stations network; 1 station per 2000 ha	Point	Past and daily checked data on rainfall, temperature, rel. humidity, etc.	Cum. rainfall, max/min/average temperature, cum. evapotranspiration, daily data.	Empirical models for the calculation of bioclimatic indices; zonal statistics	Surfaces classified according to bioclimatic index values
Land use	Raw data from weather stations network; 1 station per 2000 ha	Grid	Past and daily checked data on rainfall, temperature, rel. humidity, etc.	Cum. rainfall, max/min/average temperature, daily data.	Comparison between matrices of data	Land use changes over time, evaluation of ancient (most traditional) olive groves
Land use	Land use map /1:50,000 (1954 Touring, 2001 Campania region, 2011 new survey from Soilconsweb project, LULC 2017 from ISPRA)	Polygon	Land use classification on several spatial scales	Land use mapping units		
Biodiversity	Spatial variability of land use; soil quality biodiversity based on pedofauna sampling (Buscemi, 2016)	Polygon/Grid	Landscape classified according to different land use and soil biodiversity	Mapping units and zones according to indices of: Shannon, QBS, New Landscape Biodiversity (NLBI)	Clipping spatial data from database	Surfaces classified according to landscape and soil biodiversity

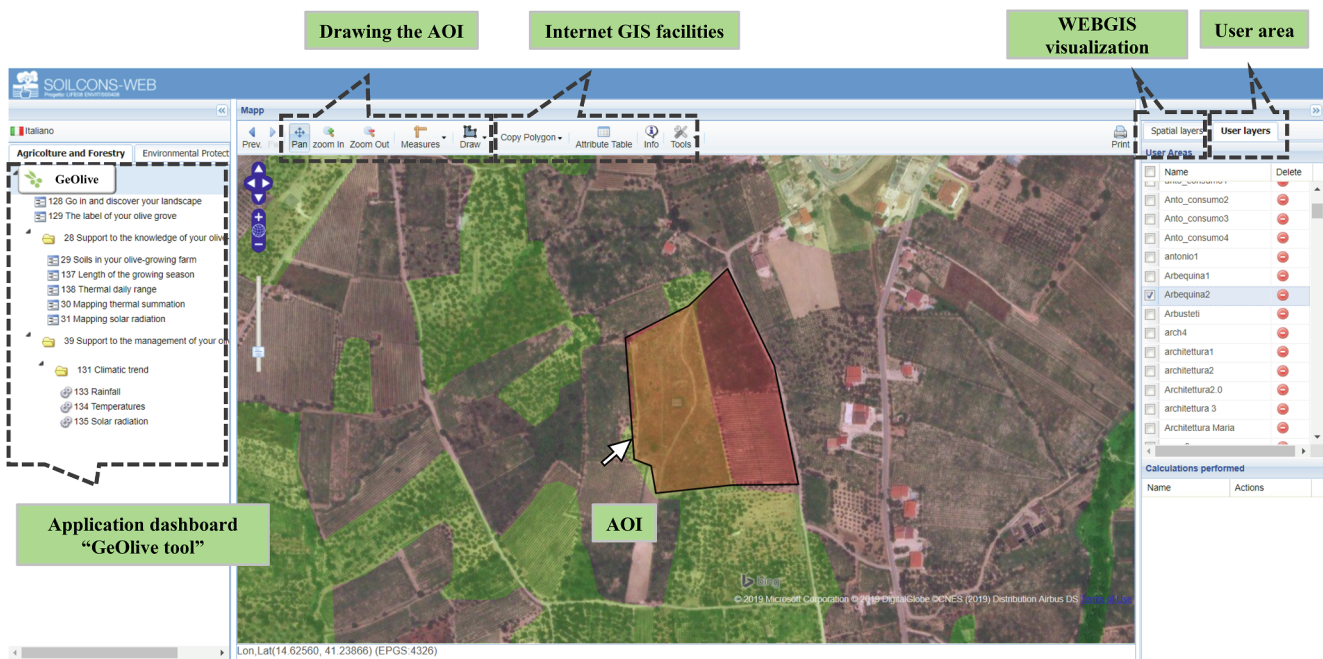


Fig. 2. General outline of the dashboard. Abbr. AOI: Area Of Interest.

agronomic and yield quality issues. These are based on empirical relationships of thermal conditions and solar radiation levels. By using time series of climate data, the following data on elements with a great impact on the local adaptation of olive trees were preprocessed: growing degree days during the summer season (GDD) and length of the growing period (LGP) with an active threshold of 12 °C, daily temperature (TE) and potential solar radiation. To highlight the importance of these parameters, we here emphasize that, due to the topographic complexity of Valle Telesina, the above indices show a large spatial variability ranging from the hilly areas to the plains and valleys (e.g. LGP ranges from 150 to 250 days, GDD ranges from 650 to 2,000 °C).

The use of SWAP for simulating plant water stress. This model has been applied to produce analysis of olive adaptability (several cultivars) to current and future climatic conditions. The issue refers to the capacity of different cultivars to react/adapt to drought conditions in a context of climate change and the increasing use of irrigation (and costs) in olive growing. (see [supplementary material](#) for details).

A completely different approach is required for ongoing dynamic processes (such as the current climatic season) where off-line procedures cannot be applied and, rather, models operating in real time and allowing “on the fly” processing through the web need to be implemented. For instance, this is the case when the user wants to know – for a specific AOI – the potential water stress that may occur in the olive grove over a specified time period. Basically, soil and climate input data stored in the geo-database are “picked up” by automatic routines, so allowing the application of the model throughout the study area. The combination of SWAP and current climate data in our DSS is rather innovative and important because, to our knowledge, web-based truly “geospatial” DSS, delivering “on-the fly” dynamic simulations based on current climate data are not yet available for olive growing.

If necessary, according to the user requests, some of the above models can run together in a sort of modelling cluster (MC). Below are some details of the most important and requested by stakeholders MC procedures employed in the GeOlive tool.

4.5.1. MC1 – reporting the key parameters of olive groves

The module function is mainly based on two procedures: (i) it can calculate several zonal statistics regarding the selected AOI (e.g. min, max, mean value, etc.) on both vector and raster spatial layers stored in

the geo-database (e.g. digital elevation model, geology and soil maps, land use maps, climate maps, bioclimatic maps such as GDD, LGP, TE, etc.), and (ii) report these data within tables and sections of an exportable .pdf file using a PDF generator (FPDF) thus producing a sort of “identity card” of the selected AOI.

4.5.2. MC2 – current climate trend of my olive grove landscape

Temperatures and rainfall affect plant metabolism, phenology and particularly plant diseases and, therefore, are key factors for a quality olive grove (Pannelli et al., 1994; Romero et al., 2003). Nevertheless, it is quite normal for olive growers not to have their own on-site agrometeorological stations so as to monitor their olive groves locally for precision management. In this context, MC2 has been developed to allow users to select both the area of interest and time windows within which to query the system on local climate data. WeatherProg routines process stacks of time-varying digital daily climatic maps (data cubes) for each climatic variable in the geodatabase and these are, in turn, clipped on-the-fly to run the calculations requested by the end users in real-time. Through PostGis functionalities consisting of clipping climate maps using the AOI as a crop area and producing zonal pixel-based statistics (for each daily map to be processed), the output for the users is made up of graphs depicting the climate trends (e.g. rains) within the time windows selected. Maps are generated thanks to OpenLayers, a browser-based JavaScript framework.

4.5.3. MC3 – current trend of potential relative evapotranspiration deficit index (RETD) of olive grove landscape

Olive responses to water stress seasons have marked effects on yield performances and oil quality (Palese et al., 2010; Di Vaio et al., 2013; Gómez del Campo et al., 2014). Monitoring environmental parameters relating to olive grove water stress could represent one of the major challenges for this high-value crop, particularly considering the beneficial effects of irrigation on olive quantity/quality (Iniesta et al., 2009; Ruiz Sánchez et al., 2010).

Therefore, a modelling cluster in GeOlive aimed at the calculation of a water deficit index, as a means to characterize the local environment or to compare different AOIs and their general suitability for olive groves, was implemented.

The GeOlive “on-the fly” module uses the SWAP model (recoded for

Table 2
(Adapted from [Terribile et al., 2017](#)). Details for modeling implemented in the GeOlive tool.

Modeling chain	Application	Main functionalities	Required implementing activity (new codes to be written)	Examples of input parameters	Examples of output in the S-DSS	On the fly operation
General description	(MC1) Basic AOI data	Collecting environmental data describing the AOI	Writing new codes: (i) development of the WeatherProg engine; (ii) clip of data and of WeatherProg output (vector, raster and table format) on the base of AOI, and spatial statistics.	(i) raw weather data from sensors at hourly or daily time steps; (ii) raster maps of weather data; (iii) raster, vector and table data relating to soil type, elevation, land use, geology, bioclimatic indices, administrative units, etc.;	Exportable reports in PDF format containing environmental data relating to AOI description, including climate data (average values and last acquisition data) and soil profile pictures.	Y
Planning	(MC1) Support for the analysis of Olive groves	Mapping main physical and environmental parameters	Writing new codes: clip of data on the base of AOI and basic spatial statistics; Applying: (i) GIS capabilities for calculation of environmental parameters (physical parameters) relating to olive growing; (ii) empirical models for bioclimatic index calculation;	Raster and vector data relating to elevation, aspect, soil, geology, bioclimatic indices, climate data, etc.	Vector and raster maps (provided with dynamic legends appropriate to the AOI dimension) depicting the parameters requested (e.g. length of growing period (LGP), daily temperature excursions (TE), growing degree days (GDD), potential solar radiation)	N
Management	(MC2) Climate trends (e.g. support for pest management)	Depicting through graphs and mapping climate data variation over time (daily time step)	Writing new codes: (i) development of the WeatherProg engine; (ii) collecting “map stacks” of climate data, including last acquisition, on the basis of variable time periods; (iii) adapting and rewriting pre-existing SWAP model codes; (iv) “pick up” of SWAP model input data from the geo-database on the basis of the AOI; (v) clip of data on the basis of AOI and basic spatial statistics;	Raster maps of weather data and evapotranspiration process	Graphs depicting climate trends on daily base (temperatures, rain, potential evapotranspiration) referring to required time periods;	Y
	(MC3) Trends of potential Relative Evapotranspiration Deficit Index (RETD)	Calculating RETD trends (daily time step)	Writing new codes: (i) development of the WeatherProg engine; (ii) collecting “maps stacks” of climate data, including last acquisition, on the base of variable time periods; (iii) adapting and rewriting pre-existing SWAP model codes; (iv) “pick up” of SWAP model input data from the geo-database on the base of the AOI; (v) clip of data on the base of AOI and basic spatial statistics;	(i) raster maps of weather data; (ii) raster, vector and table data relating to soil properties;	Data values related to water stress trends on a daily basis	Y

GeOlive) to estimate the current RETD (Relative Evapotranspiration Deficit Index) within the user defined AOI.

Accordingly, we defined the daily RETD with the following:

$$RETD(\%) = \left[1 - \left(\frac{ET_{act}}{ET_{max}} \right) \right] \times 100 \tag{1}$$

where ET_{act} is the actual crop evapotranspiration (mm) and ET_{max} is the maximum crop evapotranspiration (mm), i.e. evapotranspiration at optimum soil water availability.

The sum of daily RETD within specific periods represents the total cumulated stress:

$$RETD_{cum} = \frac{\int_{t_1}^{t_2} 1 - \left(\frac{ET_{act}}{ET_{max}} \right) \cdot dt}{t_2 - t_1} \times 100 \tag{2}$$

where t_1 and t_2 represent the first and the last day of the period considered for the simulation, respectively.

The MC3 operates according to the following steps: (i) the user defines the AOI; (ii) the AOI constitutes the spatial reference for the PostGis processing; then, soil and plant parameters stored in the geodatabase are “picked up” and used as data input for the model (so soil and plant parameters are statistically representative of the AOD); (iii) climate data input (rain and evapotranspiration) are defined (last 2 years to current day) and refer to the “stack” of daily climate maps produced (WeatherProg), while the crop growth parameters describe the development (in terms of Leaf Area Index and roots depth) of an olive tree, as obtained by Alfieri et al., (2019); (iv) using the above inputs, the model runs on a daily basis and produces potential RETD values. These data are produced for each soil type within the AOI and added in table format to the exportable .pdf file as an output of the MC1 process described above.

The following use cases detailed in supplementary materials, aim to provide some practical examples of the operational use of the GeOlive system.

5. GeOlive use cases

The GeOlive tool is fully active within the administrative boundaries of Valle Telesina (South Italy, Benevento) (Fig. 3). The area has a complex landscape with great spatial variability in soils, land use and climate. It has an extension of about 20,000 ha over 13 municipalities. Here olive growing occupies more than 3,000 ha, generally on the hills where olive cultivation has a long tradition. Valle Telesina is part of the larger basin of the Calore river which crosses the whole area on a West-

East trajectory. The area includes 60 Soil Typological Units, the main soil types includes Silandic, Melanic, Mollic, Eutrosilic, Vitric Andosols, Haplic and Vertic Calcisols, Vertic Leptic Cambisol, Haplic Regosol, Vitric Phaeozem, Vitric Luvisol, Calcic Kastanozem, Vitric Kastanozem, Fluvic Cambisol (IUSS Working Group WRB, 2015). Soil types are spatially aggregated into 47 Soil Mapping Units.

The users applying the GeOlive DSS can access several tools; these tools refer to olive grove (i) planning, (ii) management and (iii) spatial planning.

Planning tools are intended to assist in the making of the best planning choices; management tools are designed to support the farmer in his operational activities; finally, spatial planning tools support planners in terms of giving value to the landscaping function of areas of olive groves. The tools are fully described in supplementary materials by means of some use cases summarized below (from i to v). Figs. 4 and 5 show respectively the general scheme and the steps the user has to follow to address specific issues.

5.1. Case 1: Planning

Issue i) refers to an olive farmer who aims to improve the marketing of his high-quality olive oil by providing terroir-like information about his farms applying the MC1 process through the “Label of your Olive growing” tool (Fig. 4);

Issue ii) refers to a farmer who may need support to evaluate the suitability of his AOI (e.g. his farm) for a specific olive tree variety. In Table 3 and Fig. 5 (right side), some data are shown that the user would obtain by applying the procedure to two AOIs to be compared.

Issue iii) refers to the case of an olive farmer who has to evaluate whether a specific AOI is suitable for organic management. Here, the user can access several applications for information in order to evaluate the presence of environmental characteristics facilitating organic farming.

5.2. Case 2: Agricultural management

GeOlive provides tools to support management by monitoring in real time key parameters closely relating to improving the quality of oil production in defined AOIs.

Issue iv) refers to an olive grower who plans to monitor local climate conditions so as to prevent intensive olive fly attacks (*Bactrocera oleae*). So, the farmer may use the MC2 routines to monitor daily temperatures and rainfall within his/her AOI (farm). In Fig. 6, a composite image is presented showing an example of how the farmer could monitor his

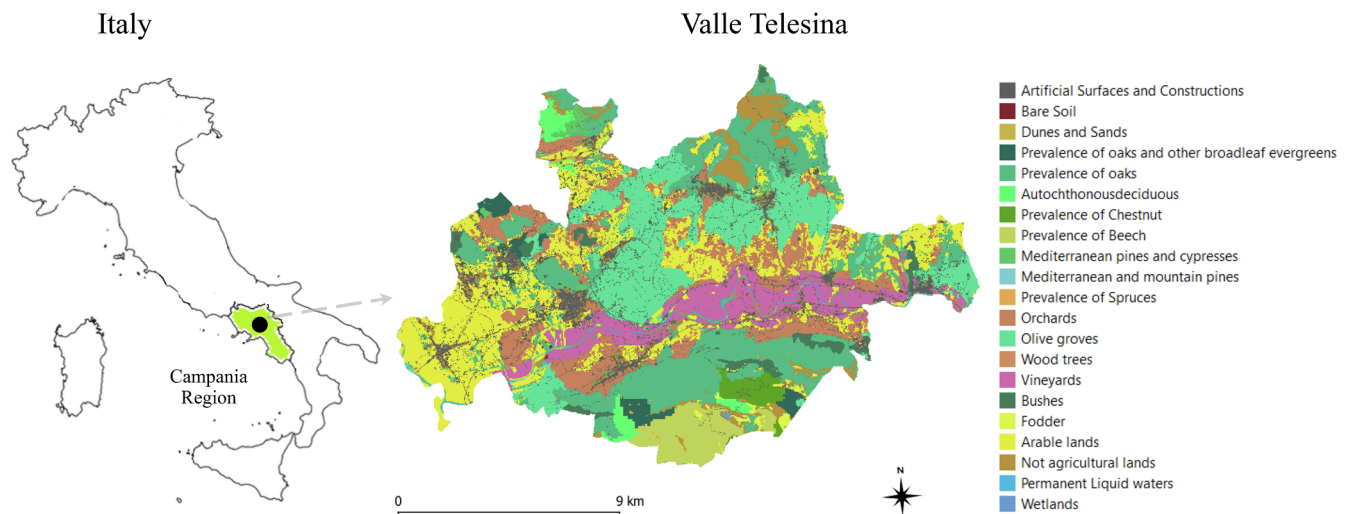


Fig. 3. The study site located in “Valle Telesina” – South Italy, Benevento-. Right side map shows Land Use Land Cover Map LULC 2017 edited by ISPRA - Italian National Institute for Environmental Protection and Research.

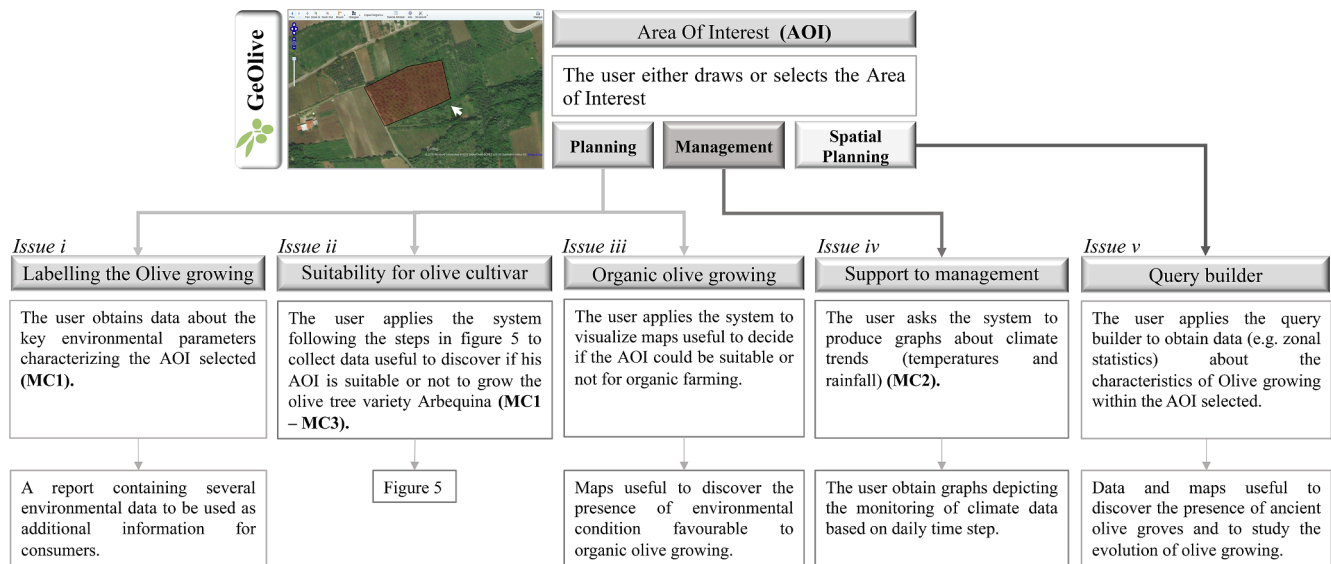


Fig. 4. Flow chart of the GeOlive tool. AOI: Area Of Interest; MC: Modelling Cluster.

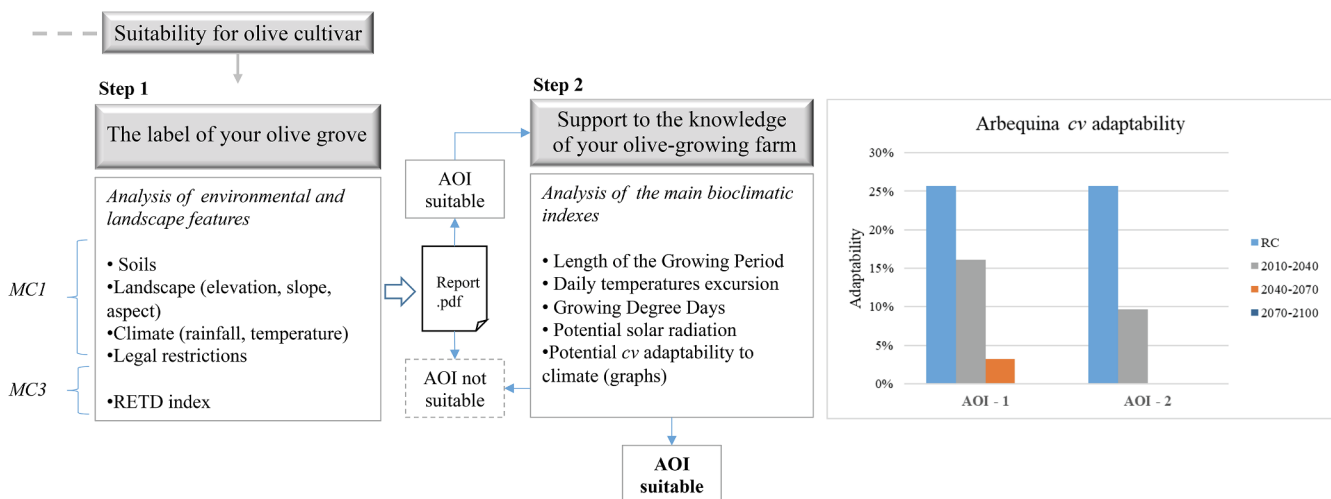


Fig. 5. Left: flow chart of the GeOlive tool: “Suitability for olive cultivar”. AOI: Area Of Interest; MC: Modelling Cluster; RETD Relative Evapotranspiration Deficit; Right: graphs of the cv adaptability to actual and future climate. In AOI-1 the model predicts greater adaptability and more durable over time. The estimated adaptability decreases to zero for future scenario 2070–2100 in both AOIs. This is due to the model setting related to water management which is of rainfed type.

area of interest.

5.3. Case 3: Olive grove and spatial planning

Issue v) refers to the case of a spatial planner who has to develop or review the Municipal Urban Plan (also named PUC) in Valle Telesina. In this use case, the GeOlive tool has been applied to the municipality of San Lorenzo Maggiore where the olive growing area occupies almost 30% of total surface, but is highly fragmented and interconnected with urban settlements. In Fig. 7, an example is shown of the spatial output obtained.

6. Discussions and conclusions

Despite the general agreement that sustainable high-quality olive growing – combining high income and land conservation – can play a crucial role for many areas, including inland and marginal areas, there is an evident lack of an operational tool which may help farmers to pursue this desired goal. DSSs can indeed produce such tools to support farmers in their olive growing, but most DSSs are designed to support

individual farms with a large use of high-technology and sensors and, so, they fail to deliver on the scale of the olive growing landscape, by losing the connection between single farms and their environmental surroundings.

In this paper, we have addressed the above issues considering also other connected environmental and socio-economic factors.

More specifically, we have attempted to demonstrate that Geospatial Cyberinfrastructure might be the way ahead for a new approach to address olive growing on the landscape scale by providing a multi-user, multiscale tool which is applicable to contexts ranging from entire districts to single farms.

In this respect, our GeOlive tool does not require as a “must” a landscape with “n” farms, each of which has sensors and technologies to support decision making, but rather aims at producing a freely available evenly-distributed geospatial system to support the entire olive cultivation landscape.

The platform must be considered flexible and open to further implementation; therefore, it is important here to discuss some key points of the approach, some of the lessons learned and some problems to be better addressed. Amongst these, we aim to highlight the following:

Table 3
Output of the “The label of your olive grove” tool applied in AOI-1 and AOI-2.

Site		AOI-1	AOI-2
Surface area [ha]		3.5	3.2
Municipality		San Lorenzello (BN)	San Lorenzo Maggiore (BN)
Elevation (average) [m]		207	215
Slope (average)		3%	10%
Aspect (average)		West	West
Annual rainfall [mm]		986	1510
Annual temperature [°C]	Mean	14.8	15.0
	Min	−8.5	−7.3
	Max	39.0	39.2
Length of growing season (average) [days]		234	235
Daily thermal excursion (average) [°C]		11.6	11.7
Geology		Igimbrites	Sands and gravel of fluvial terraces: 31%; Limestone: 69% of the area
Land Use 2017		Vineyards (90%); Shrubs and bushes (10%)	Olives groves (49%); Vineyards (51%)
Soils		Soils from flat to softly undulating, superficial stoniness absent, very deep, excessively drained, medium texture, neutral (pH), not calcareous. They have weakly expressed andic properties and below the surface horizon an accumulation of illuvial clay	Soils gently undulating, superficial stoniness absent, very deep, well drained, texture from fine to moderately fine, moderately alkaline on the surface and strongly alkaline in depth, calcareous on the surface, very calcareous in depth. They have deep horizons with calcium carbonate accumulation.
Annual solar radiation (average) [kWh ^{−2}]	1114 - mean of the whole Telesina Valley	1140	1180
RETD index (average) [%]	44 - mean of the whole Telesina Valley	37.5	38.3

- There is a large variability of users and this greatly affects the assumed usefulness of GeOlive. There are cases where territories are mostly managed by elderly olive farmers who are not at all inclined

to the use of computer media, like where there are young and dynamic farmers.

- In the GeOlive approach, the olive grove plays a central role within

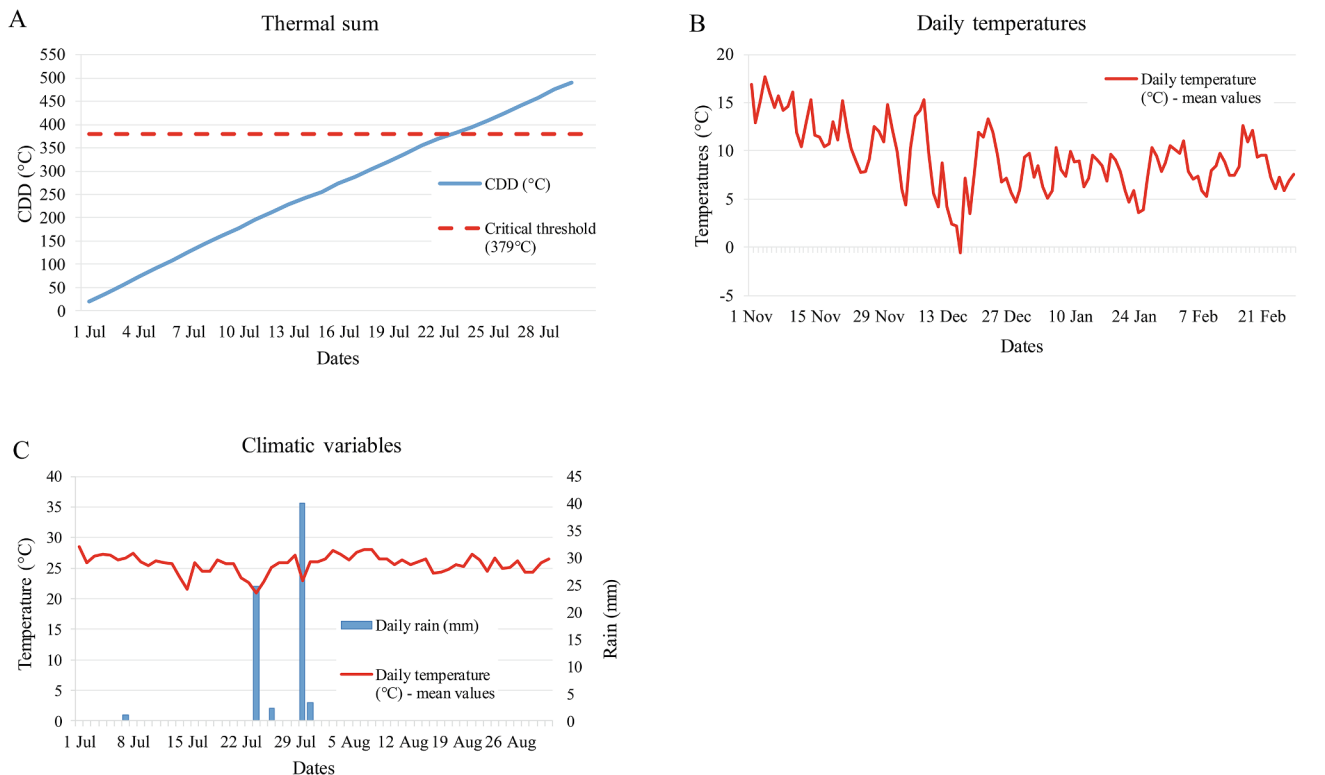


Fig 6. Graphs produced as output of “Climate trends” tool applied in a defined AOI thanks to MC2 modelling. The user can get monitoring data referred to temperatures and rains. A: solid line – Cumulative Degree Days with a lower threshold of 9 °C starting from the day of oviposition (1-July), dashed line – critical thermal sum (379 °DD); B: daily temperatures (mean values) recorded during the period Nov-Feb; C: solid line - daily temperatures (mean values) during the period Jul-Aug, bars- daily rain.

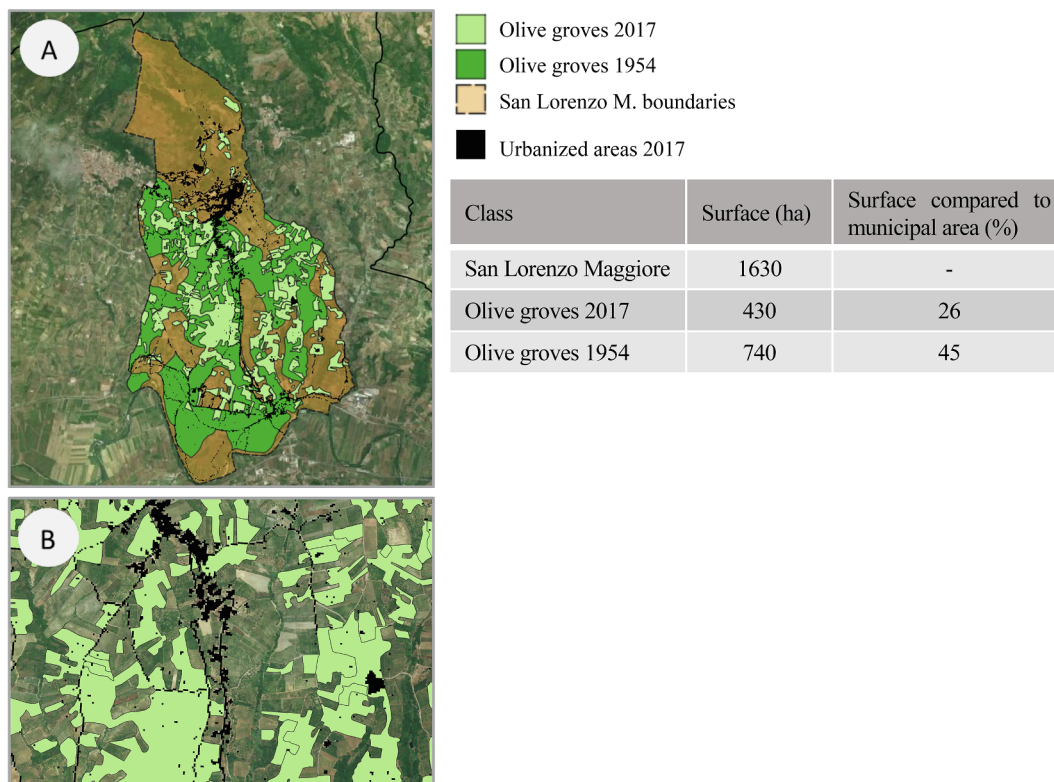


Fig. 7. Maps and statistics on land use class “Olive” (1954 – 2017) for the Municipality of San Lorenzo Maggiore, (Valle Telesina). A: Olive growing area from ‘54 to today has decreased of almost 30% and it has spread in new zones in the north and sud-west part of the Municipality. In the central part of the olive-growing area are still present old olive orchards; B: detail of the map: urban settlements and olive groves appear strongly interconnected; Data sources: Olive groves 2017 (National Land Cover map edited by ISPRA - Italian National Institute for Environmental Protection and Research); Olive groves 1954 (Land Use map 1954-Touring Club Italy); Municipality area (Geoportal service from Campania Region);

an integrated and multilevel framework. Indeed, GeOlive implements the theme of the olive grove in strategic landscape planning, as in the case of the issue of fragmentation of rural land.

- On a more general theme, other key technical lessons which have been learned refer to the importance of using free, open-source geospatial libraries and programs that allow the potential involvement of a large community of developers and the flexibility/interoperability of the system. This places GeOlive at the centre of an issue of great relevance, namely a paradigm shift that is extensively affecting the world of decision support systems as they move from patented proprietary and monolithic systems towards open-source frameworks that are easily adaptable to end-users’ needs, easily improved through modular structures and not in need of local installations and updates.

Even considering the above further developments of the platform is indeed required and it must include:

- On-the-fly simulation of crop modelling to support everyday crop management.
- Modelling of plant disease. This is a key issue in the development of S-DSSs to have an application from field to landscape scales. In attempting to tackle this issue, GeOlive implements an early version of an empirical model based only on climate data, the effective functioning and usability of which will need additional calibration and validation tests.
- Application over wider areas. In order to face this change of scale, it is important to address: (i) the appropriate balance between the quality/availability of input data and the resolution of information provided on a large spatial scale; (ii) the need for high-performance computing systems to process large amounts of data in real time.

- Input data. For the future we foresee that it will be important to implement DSSs where new local input data or sensors (e.g. user data, farm weather stations, etc.) will improve the spatial inference of the entire system with regards to the landscape. In such a way, “the action of the individual will benefit the community”, both in terms of quality of services and costs.
- Contribution and feedback from end-users and stakeholders are fundamental to developing suitable dashboards and useful data processing. In this respect, direct meetings involving potential users were organized during the early stage of the SOILCONSWEB project, but much larger and younger user communities should be involved in the future for evaluating the socioeconomic impact at local scale.

Thus, it can be concluded that it is possible to combine into a single Geospatial DSS system the critical ensemble of the following features: (i) user friendly (having complexity is embedded); (ii) operational olive growing multi-functionality; (iii) potential adaptability to the needs of many end-user including olive growing districts, cooperatives and single farmers.

Finally, an important issue to be raised here is the rather low cost of implementation (not considering data, calibration and validation) when applying GeOlive to new areas.

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Appendix A. Supplementary material

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.compag.2019.105143>.

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