EARSC discussion topics on the Consultation on Soil Health - protecting, sustainably managing and restoring EU soils

The European Association of Remote Sensing Companies (EARSC) is a trade association based in Brussels, representing the European downstream services sector. EARSC counts more than 135 members across 25 countries of Europe.

EARSC welcomes the EU Soil Strategy for 2030 aiming to have all EU soils in a healthy condition by 2050. The European Commission is consulting on this legislative proposal on soil health complementing the Nature Restoration Law and, ensuring synergies with climate change mitigation and adaptation actions.

The European Commission is demonstrating unprecedented leadership with the Green Deal flagship to tackle climate change and will require an abundance of resources including viable data and information which will allow governments to identify risks, tailor policy response and resource allocation, monitor progress and identify trends.

The green transition must be complemented by the continued use and improvement of new datasets. By combining satellite data with measurements from ground-based instruments and other technologies such as artificial intelligence and machine learning, it is possible to have a wide range of applications and services in a variety of applications. The following lines provide an overview of the EO services that will be of interest to the soil health discussions.

BACKGROUND CONSIDERATIONS

Soil Health is a very wide topic and there are lots of definitions related to the users' applications. Stating the scope, limits and intention of the application is essential (e.g: what's soil health?)

Earth Observation, as an objective and cost-effective data source, is an important tool to inform on soil health and contribute to building efficient soil monitoring systems. With its capacity to process large amounts of data, the EO sector can provide enhanced solutions and expertise on soil properties.

TECHNOLOGY FEASIBILITY

Soil Organic Carbon (SOC) is one of the major indicators for soil health and there are currently significative activities such as the WORLDSOILS[1] project aiming to develop a **pre-operational Soil Monitoring System** to provide yearly estimations of Soil Organic Carbon (SOC) at global scale, exploiting **space-based EO data** leveraging large soil data archives and modelling techniques to improve the spatial resolution and accuracy of SOC maps. SOC is an indicator of overall **soil quality** associated with nutrient cycling and its aggregate stability and structure with direct implications for water infiltration, soil biodiversity, vulnerability to erosion, and ultimately the productivity of vegetation, and in agricultural contexts, yields. EO methods can be used to estimate aboveground carbon stocks, but SOC will be used until methods to measure total terrestrial carbon stock are operational and robust.

Mapping soil properties:
Soil is a complex equation that requires many specifications: chemical, physical, biological, environmental, geographical and a soil health policy definition should avoid confusing frameworks or requirements.

The **proximal models** are based on large **Soil Spectral Libraries** (SSL) data and a data science approach. High spectral resolution enables high quality-precision end products, therefore the synergistic use of multispectral images (i.e., Sentinel-2), VHR spatial resolution (UAVs, Worldview) and hyperspectral sensors (e.g. PRISMA, DESIS, EnMAP) could be used for the detection of key factors in soil analysis: bare soil pixels, semi-vegetated pixels, permanently vegetated pixels, monitoring of low-scale features in agricultural farms.

i. for areas covered by permanent vegetation, **Digital Soil Mapping** (DSM) relying on empirical relationships between measured soil properties and spatially distributed co-variates is the most suitable method.
ii. for exposed soils (mainly cropland), imaging spectrometry based on chemometric techniques is the best technique. DSM techniques use legacy in situ soil data and relate them to spatially explicit environmental information describing the so-called SCORPAN factors (soil, climate, organisms, relief, parent material, age and site).

Scale matters: Soil parameters measured in-situ do not offer a continuum whereas remote sensing technologies offer the desired scanned continuity. Yet, satellite pixel size and associated terrain scales should be clearly specified, also for the sake of calculating uncertainties. Correlation methodologies between satellite data and in-situ measurements should be well established. There is a growing awareness amongst policymakers that reliable and accurate soil monitoring information is required at scales ranging from regional to global to support ecosystem functions and services in a sustainable manner.

Soil SOC Monitoring, Reporting and Verification (MRV) system: EO soil products should identify the minimum set of methodological requirements and model parameters to implement a robust, transparent, and cost-effective MRV service temporal coverage with sensors from different families: e.g. SAR, Multispectral, Hyperspectral and LIDAR. An EO based system that can integrate both indirect predictions of SOC for permanently vegetated areas through Digital Surface Models (DSM) techniques and direct prediction for exposed soils including croplands through imaging spectroscopy techniques transferred to multispectral systems, supported by earth observation information and using in situ soil data. The accuracy of the SOC prediction including its confidence intervals should meet the requirements of users, such as stakeholders responsible for reporting on soils, policy makers

[1] WORLDSOILS is part of the European Space Agency's (ESA) Earth Observation Strategy 2040 and is ESA's Earth Observation Envelope Programme backbone. he consortium is led by the GMV company (Madrid, Spain) and includes: ISRIC - World Soil Information, DLR (German Aerospace Center), GFZ (German Research Center for Geosciences), UCL (Catholic University of Louvain), CZU (Czech University of Life Sciences), AUTh (Aristotle University of Thessaloniki) as partners and Tel Aviv University (TAU) as external support contractor.

designing and evaluating policies to increase SOC stocks, land users and owners. Given the rapid developments in sensor specifications and in processing capacities, the system should be able to evolve in the quality of the SOC predictions and accommodate other soil properties in the future.

OPERATIONAL SERVICES

The EO practice is ready by now to produce a catalogue/portfolio of services to improve soil management practices, to support both agriculture and soil conservation objectives. EO based soil services and products should seek to evaluate how **Carbon farming practices drive C flux dynamics** in given **land use, land-use change and forestry** (LULUCF) classes. To understand these services, the first step entails defining the technical specifications of the EO based product, the specific moment to be used in the agri-cycle, the verification means.

• Accuracy • Archive Length • Format • Input data • Main applications • Minimum Mapping Unit • Output legend scale • Output format • Output uncertainties	• Product Description • Requires Field Data • Spatial coverage • Spatial resolution • Temporal coverage • Uncertainties • Update Frequency • Validation

EO services can be beneficial at the Commission and Member State level to lead the way in establishing measurement and reporting tools to monitor the health of the EU's soils by leveraging the EO-based existing operational solutions. EO could be a tool to support cost-effectiveness collection of agricultural and rural data by optimising sampling designs and support to field surveys. EO could be used to quantify the amount of agricultural area, using land-use/land-cover products.

Land management practices	EO Service
Animal and green manure	The cultivation of **green manure** can be achieved with a time-series observation and crop-type classification. Typically the production of green manure takes place between two main crops. The application of **animal manure** can be detected with hyperspectral data, but has to be calibrated with in-situ data.
Biodiversity balance	**Land Use / Land Cover** (LULC) Biodiversity → EO based services to monitor, measure and ascertain biodiversity balance are based on multitemporal series of observations: Several images are required to include seasonal foliage conditions in the same reference year. EO products coupling for this service include: • **Biodiversity maps** which plot the intrinsic diversity of a land (either agricultural or forest) calculated through spatial indices (e.g. Simpson Index) accounting for the dominance, abundance, and uniformity of the different species. • **Habitat fragmentation** which maps and monitors the emergence of discontinuities in the vegetation of a specific habitat. The

	Habitat Fragmentation product is obtained by classifying spatial patterns of LULC patches and evaluating LULC densities. **Soil Biodiversity** → Hyperspectral data, with their detailed spectral information at different wavelengths, offer multiple ways to assess biodiversity. Content of biota (abiotic and biotic stress detection)> combinations of field data and different remote sensing techniques are needed.
Bush and tree fallows	The **growth of bushes and trees** follows natural succession on fallow land. With time series observation it is possible to proof whether this process is ongoing or disturbed.
Compost / fertilisation	Variable rate **fertilisation** can be supported by monitoring crop status with EO spectral indexes for detecting growth differences within single plots or by comparing the average status of the crop with the status measured in other plots cultivated with the same crop, in order to identify parts of the cultivation or full plots that could require a differentiated fertilisation. Additional support for fertilisers saving can be obtained by comparing multiyear EO derived spectral indexes in order to identify specific parts of the agricultural plots that have local stable soil features not allowing a proper growth of the crop, thus avoid not useful usage of the fertilisers
Cover crops	The use of “**cover crops**” (legumes, grasses, broadleaf plants, brassicas) is a common practice for preserving and improving soil fertility, a source of nutrients, a way to combat weeds without chemical treatments, a protection for soils prone to erosion, a means to improve soil structure, water infiltration and moisture retention. These practices are easily monitored and valued through EO by means of **LULC classification** products, leanning on field data sets guiding the calendar of the main crops and the common practices that follow thereafter with the cover crops.
Crop rotation and intercropping with nitrogen fixing crops	**Crop rotation:** Although certain crops can be cultivated for years on the same plot without yield degradation like corn, crop rotation has a positive impact on soil health. If a scheme is in place, which monitors the different crop-types over the seasons, we could easily analyse the crop rotation. **Intercropping/ cover cropping:** A farmer plants green manure after his main crop, to cover the soil in that period, where he does not cultivate any cash crop. This helps to prevent erosion and add organic matter. It has as well a positive effect for soil health. It does not mean that we look at plots, where farmers intercrop different crops at the same time on the same plot. EO wil help to observe if plots show bare-soil condition over a longer period (winter). In case a scheme is implemented where farmers get compensation for intercropping with green manure, it could be monitored.

Degraded areas	**Degraded areas** arise from desertification processes and also from fertility deterioration or runoff and heavy erosion. Big data bases (e.g. Soil Spectral Libraries (SSL) may be used to model each pillar. Data sets originating in field data, remote sensing data, National soil monitoring systems, LUCAS, the EJP SOIL LTE-network, integrated soil monitoring systems (e.g. EU Soil Observatory, Member States). **Land degradation** uses data from three sub-indicators, land cover (area), vegetation productivity (Net Primary Productivity) and carbon stock (soil organic carbon) - to estimate the degraded land area (total area of degraded land) and is able to produce spatially explicit outputs as well as tabular results. For example, satellite derived data taken by the synthetic aperture radar (SAR) Sentinel-1 and the multispectral satellite Sentinel-2 with high resolution and short revisit period have the potential to monitor the spatial distribution of soil attribute information on a large area using topography indices derived from digital elevation model (DEM), SAR indices generated by Sentinel-1, and vegetation indices.
Ecosystem services	EO are widely used for assessing the following ecosystem provisioning services: Energy, Food, Raw Materials, Water Provision, which are all relevant in the context of soil health. In a similar way, they are relevant in quantifying ecosystem regulation services such as Climate, Erosion, Flood, Water and Biological control. **Ecosystem Provisioning EO derived products:** ● **Energy:** Time series of NDVI & Leaf Area Index; Tree Cover Density; Forest Type Map. ● **Food:** Land Cover map; Crop Evapotranspiration map; Net Primary Productivity map; Nutrient Nitrogen Index (NNI) & Chlorophyll concentration map. ● **Raw Materials**: Time series of NDVI & Leaf Area Index; Land Cover map; Gross Primary Productivity map. ● **Water Provision:** NDWI time series**;** Crop Evapotranspiration; Canopy Water Status; Water deficit; irrigation water requirements; irrigated area map. **Regulating Services:** ● **Biological Control:** Land Cover and Forest Type map. ● **Climate Regulation:** Land Cover; Evapotranspiration map; Water deficit map; Soil CO2 emission. ● **Erosion & Flood regulation:** Land Cover map; Tree Cover Density map; Forest Type map. ● **Gas Regulation:** Land Cover map; Soil CO2 emission map; Nutrient Nitrogen Index map.
Fallow rotations	In a three-field economy, **fallow land** alternates with cultivated land in a multi-year rhythm. Once the areas have been assigned to the owner, remote sensing methods can be used to record land use and hence fallow as one element of a crop rotation scheme.

Life green barriers, buffers with woody species	**Conservation buffers and Green Barriers** are strips of vegetation placed in the landscape to influence ecological processes and provide a variety of goods and services. The benefits of conservation buffers include protecting soil resources, improving air and water quality, enhancing fish and wildlife habitat, and beautifying the landscape. In addition, the design and the monitoring of green barriers benefit from Earth Observation products such as **Land Use Land Cover maps and changes**; T**ree Cover Density maps**; **Land Take Map** (losses/gains of agricultural land), and urban tree mapping.
Minimum tillage	With SAR data we can observe the roughness of the surface and estimate where farmers use methods of **minimum tillage for soil preparation**. In addition a soil type map is needed to calibrate the map product.
Mulching	Increasing use of **plastic mulch** benefits agriculture by promoting crop quality and yield, but they impact the environment and soil pollution which is becoming increasingly severe. Therefore, monitoring of plastic mulched farmland has received increasing attention. Earth Observation techniques can detect plastic mulching using **multitemporal classification** (using machine learning approaches) or time series of a satellite-derived index such as **NDBI (built-up index)**.
Ploughing/tillage intensity, grazing, and forestry	**Ploughing** operations have been used for millennia as a means of preparing soil for planting, and for root crops like potatoes, harvesting. Ploughing is an effective method for weed control, loosening hard soils, and enables soils to warm up earlier in spring. However, ploughing can result in soil organic matter (SOM) losses, as soil aggregates are broken up, exposing them to atmospheric oxygen and enabling soil microorganisms to more efficiently degrade organic matter that is either in the form of decaying vegetation like plant roots or already degraded humus. Optical and SAR remote sensing, particularly in time series, enables us to monitor tillage and planting practices, and thus, verify which farmers are indeed using conservation tillage methods.
Restoration of peatland	**Peatlands** cover about 3% of the global land area but are a key terrestrial ecosystem since they contain 20% of all global soil carbon, substantially more than the carbon stock in the global forest biomass. Peatlands can be either a carbon sink or—especially if drained—a carbon source. In the EU, more than 50% of the peatland area is in a drained state which results in the release of CO2 from the fossil carbon store. Paludiculture and rewetting grassland on drained peat soils is a key practice to prevent GHG emissions. EO SAR data are particularly apt for this humid environment since optical data are primarily limited to reporting on the vegetation classes and properties of the immediate peat surface. Interferometic SAR (InSAR) techniques are used to monitor peat surface motion pointing at accumulation and loss of peat. The status of the water table is yet another

	key parameter to monitor as well as vegetation structure in the wet forests. Another important product would be the wetland trend derived from soil moisture estimates.
Soil management practises	Need to access and have standardized **soil databases** containing fields under conservation agriculture. Pairing the SOC content in these fields with conventional fields under the same climate/soil conditions, is required to calculate the response ratio: (SOC conservation-SOC conventional)/SOC conventional. SOC maps compiled from remote sensing can be used to get the SOC contents in the conservation and conventional fields. At the regional scale the response ratios of these pairs are significant. **Soil properties** such as soil moisture and soil salinity could be estimated using soil moisture index (SMI) and soil salinity index (SSI), respectively. The soil moisture[2] describes how wet or dry the soil is in its topmost layer and could be measured by satellite allowing insights on soil conditions regulating air temperature and humidity. Soil moisture is recognized as an Essential Climate Variable (ECV)[3] and can be estimated using a combination of NDVI (normalized difference vegetation index) and LST (land surface temperature) data.
Terraces, contour farming	With stereoscopic data derived from SAR or optical sensors digital elevation models can be derived and indicate **terraces and/or contour farming**. Depending on the field size, sufficient spatial resolution of the data is essential.
Trees on croplands	**Trees** are permanent features in cropland and can be detected with time-series observation, since they have a different signature as cropland. With high spatial resolution the quality of the result will increase.

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[2] information on Surface Soil Moisture characteristics
[3] Global Climate Observing System (GCOS)