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The Role of Remote Sensing in Agriculture and Future Vision

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Abstract

The sustainability of agriculture became one of the key priorities for policy frameworks at global and European levels. The global initiative of the United Nations that defined the Sustainable Development Goals and the European Green Deal. Use of remote sensing to achieve sustainable practices in the entire agriculture value chain can significantly contribute to fulfil the set goals by the policy frameworks. This paper analyses the stakeholders involved in agriculture including the agri-food, public, financial and food security sectors, and their needs. In situ and virtual workshops with relevant stakeholders including an online survey served as a primary source of input for the user requirements analysis and as a platform for feedback and discussion. As a result, a set of key documents including a white paper, a policy roadmap and a strategic research agenda were published. Recommendations for future utilisation of remote sensing in agriculture are described in this paper.

Keywords

Earth observation, agriculture, white paper, strategic research agenda, policy roadmap, technology watch, hackathon, webinars, questionnaires.

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Introduction

The increasing economic, social and environmental needs of agriculture pose many challenges for the upcoming years. This topic of sustainable agriculture is closely related to the strategies of the United Nations and the European Union on sustainability. The United Nations adopted 17 Sustainable Development Goals in 2015 as part of the 2030 Agenda for Sustainable Development. The European Union presented in 2019 the European Green Deal - a roadmap to make the European economy sustainable (Campbell et al., 2018; Lampridi et al., 2019).

Agriculture comprises vital economic sectors producing food, agro-industrial feedstock, and energy and provides environmental services through managing soil, water, air, and biodiversity holistically. An overview of all these aspects is given in this publication (Baer and Birgé, 2018). Agriculture including forestry also contributes to managing and reducing risks from natural disasters such as floods, droughts, landslides, and avalanches (Sivakumar, 2005; FAO, 2020). Farming with its close contact to nature provides the socio-economic infrastructure to maintain cultural heritage. Farmers are also conservers of forests, pastures, fallow lands, and their natural resources and, in turn, of the environment (Jedlička et al., 2019; Montañana et al., 2020; Navrozidis et al., 2019; Diacono et al., 2021). Agriculture today is a composite activity involving many actors and stakeholders in agri-food chains (FAO, 2017) that produce and provide food and agricultural commodities to consumers. In addition to farmers, there are farm input suppliers, processors, transporters, and market intermediaries each playing their roles to make these chains efficient (Horizon 2020 Work Programme, 2018-2020).

More than 10 years ago the FutureFarm project (Charvat and Gnip, 2009) recognized that the agriculture sector is under a strong influence of several external drivers including climate change, demographics, energy cost, food quality and safety, policies, economical and financial instruments, sustainability, and public opinion. Interactions between different drivers influence the agri-production and the food market is then dependent on regulations and common policies.

Due to the complexity of sustainable agriculture we need to better understand all processes involved and build for each agriculture sector a new knowledge management system (Zhao et al., 2020). The main focus of paper is on the use of Earth observation, and particularly on Copernicus satellite data, in support of agriculture. This paper analyses the role of Earth observation (EO) as a knowledge management system for sustainable agriculture including its current gaps and limitations (Anderson et al., 2017; Whitcraft et al., 2015). The main focus is on Copernicus satellite data. Copernicus is a European asset for space-based monitoring of the Earth, consisting of a complex set of systems, which collect data from multiple sources: Earth observation (EO) satellites and in-situ sensors such as ground stations, airborne and sea-borne sensors. The data are processed providing users with reliable and up-to-date information through a set of services related to environmental and security issues. As it became clear, the key to unleash the huge potential of Copernicus is easy to access its data and information products. In this regard, the European Commission (EC) created the baseplate for establishing an Integrated Ground System (IGS) for Copernicus that will empower the user communities to have the maximum benefits from EO data and information (Annex 1 to the GA, Part B EO4AGRI). EO data needs to be augmented with local expertise and this means that a deep cooperation model needs to be incorporated.

The research in this paper was performed during the EO4Agri project funded by the H2020 programme. The main objective of this paper is to catalyse the evolution of the European capacity for improving operational agriculture monitoring from local to global levels based on information derived from Copernicus satellite observation data and through exploitation of associated geospatial and socio-economic information services.

Materials and methods chapter introduces the research methods used to gather and analyse gaps in exploitation of EO data for agriculture including the methodology for user requirements collection, stakeholder analysis, online survey and policy and implementation frameworks. Results and discussion chapter presents the results in the form of a white paper and set of recommendations related to technology improvements, scientific priorities and organisation related issues.

Materials and methods

EO4Agri methodology for user requirements collection

The EO4Agri methodology was initially based on Foresight approach (Crehan and Harper, 2008). The goal was not to create new user requirements, but to make sense of the great number of requirements that have been created in the past via the efforts of projects funded by EU Framework Programmes such as H2020, ESA or ad-hoc projects and programmes funded by EU member states. Foresight is a strategic management tool, originally employed in the public sector as an aid in the design of research programmes. Nowadays, it is much more widely applied, not only in the public but in the private sector as well. Typically, a foresight exercise produces outputs such as vision statements, roadmaps and actions plans for implementation. In general, a foresight exercise involves:

- A systematic approach to generate knowledge about the future - insights about future Copernicus services and how these will benefit the four focus groups of the EO4Agri project, namely the agrifood, public, financial and food security sectors. These four groups are using services of technical providers including infrastructure providers, software providers and EO data analytics sector;
- A wide range of actors relevant to the domain of focus of the activity including decision-makers and domain experts, as well as enablers, beneficiaries and other stakeholders from the focus groups mentioned above. The purpose of their participation is to help them learn about the domain or focus of the activity, understand how change happens in that domain, contribute to the shaping of the evolution of that domain, and get ready to playa part in the implementation of recommendations that might emerge from the activity;

The outputs of the four focus groups were integrated into a set of key documents including a white paper, strategic research agenda (SRA), policy roadmap and a collaboration framework presented as results in this paper. This set of documents should help to mobilise and structure support for the further development of Copernicus services with a view to accelerating the process of the common agriculture policy (CAP) reform, improving the livelihood of farmers in Europe and increasing Europe's overall level of resilience and security of food systems in Europe (Crehan et al., 2019).

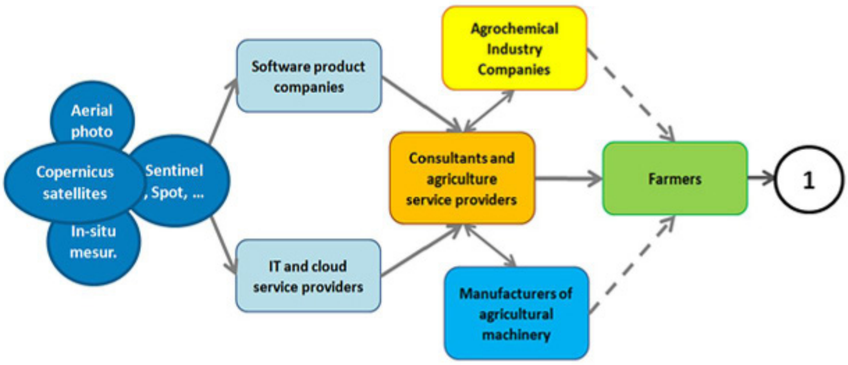
Stakeholder analysis

EO4Agri performed an analysis of the needs of different groups of stakeholders from the four focus areas including agri-food, public, financial and food security. These areas are connected with agriculture, not only on the level of production of agricultural products and food, but also on the level of developing policies for agriculture and financing (CAP payment system). The four focus groups include:

- Agri-food sector - agricultural producers, service providers, advisers, machinery, and food sectors that use data-intensive services to improve their productivity in both agricultural production and business administration. The agri-food sector is composed of different players with different interests. These users can be subdivided into:

- A subgroup connected directly or indirectly with precision agriculture. This subgroup can include agricultural producers, service providers, advisers, machinery, and also the food sector. The relations between the involved stakeholder groups are depicted in Figure 1.

- A subgroup related to the analysis and prediction of the food market. Currently, customers of this information are mainly in the food industry. However, the importance of this information will grow in the future also for the primary sector concerning planning production. Figure 2 shows the relation of this group in relation



Source: Own processing.

Figure 1: data access and information services actors (EO4Agri - User Requirements and Gap Analysis in Different Sectors).

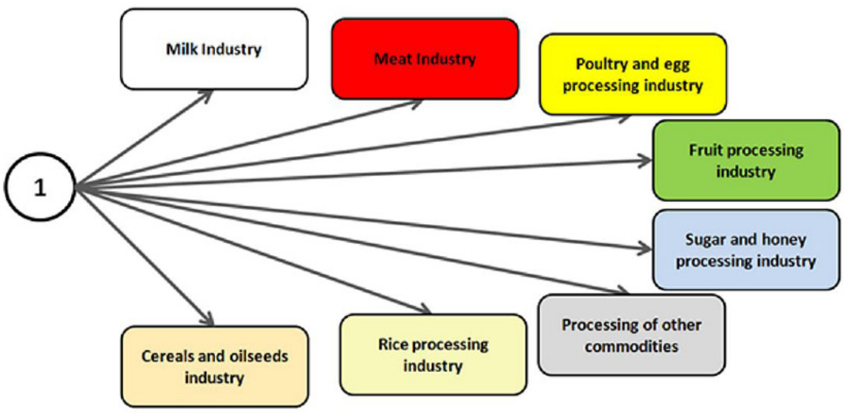


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Figure 2: Scheme of agro-industry sector and raw segments in the food industry (EO4Agri - User Requirements and Gap Analysis in Different Sectors).

to the previous group (Figure 1); Public sector organizations (and in particular national paying agencies responsible for the management of the agriculture subsidies) that use EO data as an input to agricultural policy formulation and for implementation of new farm subsidies payment systems based on monitoring (instead of inspection) and performance (instead of compliance).

- Agricultural finance institutions that provide the agri-food industry with credit and insurance services, as well as related services such as re-insurance and decision support services to commodities and derivatives traders.
- Organizations that support global food security, in particular donors involved in infrastructure and capacity building in third countries with security in food and nutrition. The activities of the donors can be related to other issues such as climate and the environment, and the management of scarce resources such as water, soil, and nitrate-based fertilizers. This group includes also local farm organizations, researchers, and the public sector in developing countries. The main incentive of this group should be to combine top-down and bottom-up approaches to solve the problem of food security.

In addition to the main four focus groups, the following stakeholder groups were identified:

- The growing industry of data service providers that transform raw data and basic services provided by Copernicus into services adapted to the needs of the four main stakeholder groups mentioned above.
- The range of services that can be provided is in constant evolution thanks to the efforts of researchers and data entrepreneurs leveraging the latest knowledge and know-how in plant and animal sciences, environment and climate sciences, economic, social, and geophysical sciences as well as new and emerging domains of ICT based on the application of artificial intelligence, machine learning or data learning in big data analytics.

Policy framework, sustainable development goals, Green Deal and Destination Earths - new challenges

Policy frameworks for utilisation of EO in agriculture are mainly given by the UN Sustainable Development Goals (SDG) at the global scale and the European Green Deal initiative and Destination Earth strategy at the European level. From the research and implementation frameworks points of view, the Group on Earth Observations (GEO) Work Programme in the global scale, Horizon Europe, Digital Strategy for Europe and Space Strategy for Europe can be identified.

The UN SDGs are a universal call to action to end poverty, protect the planet and improve the lives and prospects of everyone, everywhere. 17 goals were adopted by all UN Member States in 2015, as part of the 2030 Agenda for Sustainable Development which set out a 15-year plan to achieve the goals (Figure 3).

Source: Own processing.

Figure 3: The UN Sustainable Development Goals (The Sustainable Development Agenda).

The UN SDGs (The Sustainable Development Agenda) were approved in May 2019 by the European Commission and many of them are directly addressed to agriculture, forestry and environment.

The European Green Deal (Annex to the Communication on the European Green Deal, 2019) is a package of European Commission's measures announced in December 2019 that should ensure citizens and companies in European Union the transition to a more sustainable and greener economy by 2050. The Green Deal consists of a set of measures that enhances resource efficiency through the transition to a clean circular economy, prevents biodiversity loss and reduces pollution. These measures are related to the policy areas depicted in Figure 4.

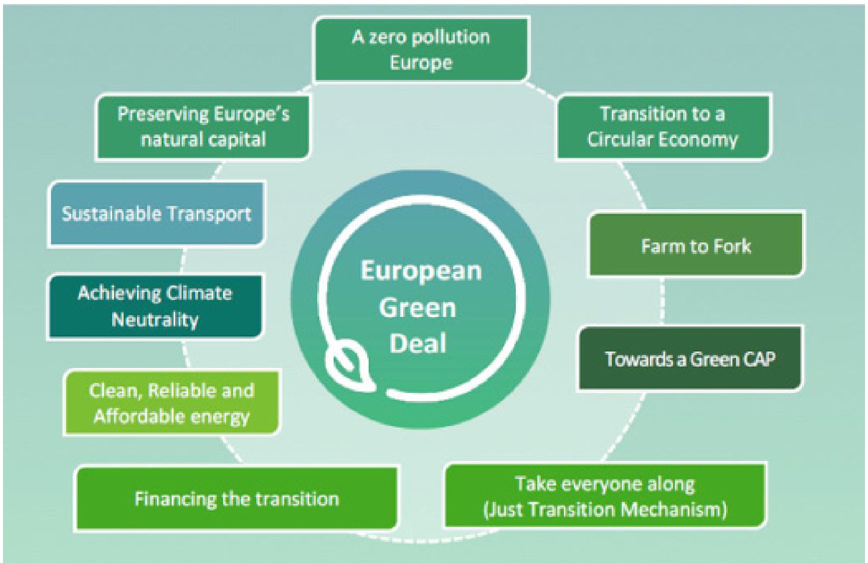
Together with publishing the Green Deal, the Commission is adopting the EU industrial strategy Destination Earth (DestinE) to address the twin challenge of the green and the digital transformation. The goal is to use the potential of the digital transformation, to be a key enabler for reaching the Green Deal objectives (The European Green Deal, 2019). The Commission is planning to initiate a 'GreenData4All', with focus on reviewing the Directive establishing an Infrastructure for Spatial Information in the EU (INSPIRE and Combine it with the Access to Environment Information Directive). As part of this will be the 'Destination Earth' initiative.

A digital twin is a digital replica of a living or non-living physical entity. The digital twins created in DestinE will give users access to high-quality information, services, models, scenarios, forecasts and visualisations (e.g., in climate modelling, weather forecasting and hurricane evolution). Digital twins are based on the integration of continuous observation, modelling and high performance simulation, resulting in highly accurate predictions of future developments.

DestinE will be implemented gradually over the next 7-10 years, starting in 2021. The operational core platform, the digital twins and services are scheduled to be developed as part of the Commission's Digital Europe programme, whilst Horizon Europe will provide research and innovation opportunities that will support the further development of DestinE. Synergies with other EU programmes, such as the Space Programme, and related national initiatives will also be explored.

Common agriculture policy and Earth observation

The CAP is the largest and most promising area of Copernicus and Galileo data use in the public sector, with farming being one of the main economic sectors using such data. The overall objective for CAP period 2021-2027 is to move from the process of controlling agricultural activity compliance with the requirements to the increase of operational efficiency. For that, the Area Monitoring System (AMS) should be in place by 2024. AMS requires joining satellite observation data (e.g., from Copernicus) with GIS data originating from territorial Land Parcel Identification Systems (LPIS).



Source: The European Green Deal, 2019.

Figure 4: European Green Deal and key policy areas.

One of the AMS parts – Checks by Monitoring (CbM) component, based on satellite data and photos sent by farmers about the carried out agricultural activities – is in the process of implementation, but implementation is not as fast as it could be.

Each EU Member State and Paying Agency has to ensure that farmers rightfully receive subsidies for their good practices. The current practice is that these entities mainly perform on-farm checks (on a randomly selected and risk analysis-based sample of farmers), the so called on-the-spot checks, and farmers with poor performances in relation to their subsidies' requirements are subject to penalties which may include exclusion from participation in funding schemes and/or monetary fines. This system partly relies on Control with Remote Sensing (CwRS) with the use of EO data: Very High Resolution – VHR and High Resolution – HR (10-20 m) images, with the possibility to use the other available satellite data as complementary data source.

On-farm checks entail serious drawbacks. They provide only a "snapshot" verification of farmers' practices and the state of their farmland, taken at a specific moment in time; they are conducted only on a small sample of farmers (in the case of farmers applying for EU subsidies); they are time-consuming and their cost is significantly high (especially when there is a need for follow up on-farm inspections); and when performed with the support of remote sensing images at fixed time windows, they are not adequate for capturing most of the temporal agronomic practices and farming activities.

Aiming to solve the above-mentioned problems and to make the farm inspections a more efficient, transparent and flexible process, the CbM concept was introduced. CbM does not represent a standard on-the-spot checks (neither CwRS), but rather a different approach of Integrated Administration and Control System (IACS) mechanism. The ambition is to completely replace on-farm checks with the use of automated checks based on EO data which enable specific "snapshot" verification of sustainable agricultural practices, applying the same logic as in the field, but through a computer-assisted environment, or the continuous (through the year) monitoring of farmland.

CbM was introduced in 2017, and the new rules came into force in May 2018. Starting from 2018 (art. 40a of EC Regulation 809/2014) the CbM became part of IACS and there is now an option to carry out CbM on 100% of beneficiaries for all eligibility requirements, using the Copernicus Sentinel satellite data, instead of checking 5% on the spot. This approach offers significant simplification and streamlining of IACS and should reduce the number of costly inspections in the field. Based on that all EU member states could use data from the EU's Copernicus Sentinel satellites and other EO data as evidence when checking farmers' fulfilment of requirements under the CAP for area-based payments (either direct payments to farmers or rural development support payments), as well as cross-compliance requirements, such as stubble burning. Other new forms of evidence such as geo-tagged photos, information from drones and relevant supporting documentation from farmers, such as seed labels, also are acceptable for the first time, as part of a broader shift towards a so-called 'monitoring approach' that will lead to a decrease in the number of on-farm checks. Visits to the field will be only necessary when the digital evidence is not sufficient to verify compliance.

Cooperation framework

In order to discuss our achievements with the broader community, EO4Agri was active in cooperation with international and European initiatives and projects. During the first year, EO4AGRI succeeded to meet most of the key players on the global and European scene. One of them is the Food and Agriculture Organization (FAO) as the main means of communication with the UN. The target of the discussion was on how EO can support global food and nutrition security and UN SDGs focused on agriculture. The cooperation with FAO was done mainly through common activity in the Agricultural Data Interest Group (IGAD) of the Research Data Alliance (RDA). EO4Agri established a contact with the Group on Earth Observations (GEO) mainly through cooperation with GEOGLAM. There was also an intensive cooperation with the Global Open Data for Agriculture and Nutrition (GODAN), where EO4Agri organised a number of meetings together with GODAN mainly on IGAD RDA meetings and also cooperated in the preparation and promotion of INSPIRE Hackathons. EO4Agri also organised a common workshop with GEOGLAM and GODAN for the GEO ministerial meeting in Canberra. The direction of the future cooperation activities with GODAN are mainly in promotion of Open Data and Capacity building. The standardisation of information in Agriculture, including EO is done through IGAD and OGC, where there is broad cooperation (Druml et al., 2020).

Analysis of previous recommendations and user requirements

One of the main tasks of the EO4Agri project was to gather recommendations from previous research projects and activities. More than 80 projects were analysed and 410 user requirements were identified and reduced to final 69 user requirements. Most analysed projects are from the Copernicus library of research projects listed in Appendix A (EO4Agri - Analysis of previous projects). The requirements were mapped to the stakeholder groups mentioned in the previous section. Requirements that are common to three or more stakeholder groups were labelled as gold requirements, overlapping requirements between two stakeholder groups were labelled as silver requirements and bronze requirements are those belonging to just one stakeholder group. The user requirements categorised as gold, silver and bronze requirements are presented in Appendix B (EO4Agri - User Requirements and Gap Analysis in Different Sectors).

Questionnaire analysis

An online questionnaire conducted by the EO4Agri project resulted in more than sixty responses that were analysed. The main results of the questionnaire include:

- 75% of respondents state that they are well acquainted with EO issues. This proportion is similar in all stakeholder groups;
- 80% of respondents who grow cereals are mainly interested in the effect of using EO information in the form of increased yield and profit and sustainability of their farming and businesses;
- 55% of respondents farm on less than 30 ha (of which 20% for less than 5 ha) and 35% farm on more than 250 ha;
- respondents see difficulties in interpreting remote sensing data and real-time unavailability of data as the main obstacles of more extensive use of EO in agriculture;
- 80% of respondents use data made available through public servers and the same number use multispectral data from Sentinel and LandSat satellites for their work at least once a week;
- RGB data is used by 40% of respondents;
- respondents consider the ground sample distance to be insufficient, when 32% of respondents require data with a ground sample distance (GSD) of less than 1 m and another 42% of respondents require data with a GSD of less than 5 m. Only 10.5% of respondents are satisfied with the current GSD of Sentinel 2 satellites which is 10, 20 and 60 m depending on the native resolution of the different spectral bands;
- two thirds of respondents state that they buy data at a price of less than 5 euro per hectare. The same number of respondents indicates that the yield from hectares will rise by up to 20 euros thanks to EO information.

  If we select only responses from the private sector, then their answers correspond to answers of other stakeholder groups with one exception. The exception is the requirement for a higher GSD which is only 50% compared to almost 90% of other stakeholder groups. A half of the respondents from the private sector are satisfied with what they work with (usually GSD = 10-30 m).

  The statistical summary and responses are in Appendix C (EO4Agri - The statistical summary and response to the main user requirements).

Analysis of outputs from workshops, webinars and hackathons

The gap analysis and foresight activities started during the year 2019 and ran until January 2020. During this period EO4Agri organized four in situ meetings in order to identify gaps with the main stakeholders groups mentioned in Stakeholder analysis and provided foresight exercises to build a new vision of EO for agriculture for future periods. The gap analysis and future vision were discussed during the follow up in-situ events including the Nairobi INSPIRE Hackathon 2019, EO4Agri Stakeholder Workshop in Pilsen, GEO Week 2019 and the GEO Ministerial Summit in Canberra, November 19OGC TC/PC Meetings - Toulouse, France 2019 and Prague Week on Big and Open Data and Innovation Hubs 2020.

The COVID 19 outbreak created an unprecedented and unpredictable situation that made it impossible to organize face-to-face conferences, workshops, seminars and hackathons. Therefore, all planned meetings and workshops were organized as fully virtual events. About ten virtual events were organised in order to validate the EO4Agri results.

During both in situ and virtual events new requirements for the agri-food and public sectors and data requirements were defined and become part of the EO4Agri recommendations and future vision (Šafář et al., 2020), (Šafář et al., 2020), (Kubíčková et al., 2021).

Agri-Food Sector:

- To assess risks/threats to sensitive ecosystems like forests and wetlands. Forests and wetlands area known as contributors to food security particularly when sustainably used;
- accurate monitoring of crop phenology to aid the application of farm inputs like fertilizers, irrigation and farm management;
- crop growth scenarios under different weather events. Growth plan – a time interval when to start planting to maximize yield as possibilities are nitrogen plan – a time interval when to insert nitrogen fertilization to maximize its effect, Insect pests alert – alert when a risk of insect pest attack is high;
- prediction of disease susceptibility of crop using the temporal crop dynamics from Earth onservation data. Using historical data of crop disease and connecting them with features extracted from Earth onservation data for generating alert of probable crop disease;
- from the analysis of the agri-food sector, the main additional requirement is to support food traceability.

Data requirements:

- Used weather data and biomass to generate index-based services for Banking and insurance such as Weather and Yield;
- sampling plots from different agro-climatic zones and monitoring growth using Earth observation techniques together with ancillary data like weather data and biophysical data;
- sentinel 1 and 2 has a spatial resolution of 20 m (some bands have 10 m) so small farmers can be benefited by the products developed using images from these satellites;
- semantic data and metadata for the description of different types of data in order to assess their applicability to EO;
- requirement for implementation of OGC standards in all EO data services;
- more focus should be on time series analysis of EO data in short and also long time periods in order to better prepare new models and adopt AI tools for future scenarios;
- metadata models and views on metadata need to be updated in order to guarantee better monitoring of data life cycles to support Destination Earth.

Public sector:

- Assessment of hydrological flows through a combination of field observations and output from satellite image analysis workflows;
- augmenting weather and climate monitoring through the use of affordable in-situ weather sensors and remote sensed weather estimates;
- LandSat can particularly be used for awareness creation on issues like land degradation and land-use change and its influence on land health and the potential areas that can be used for farming;
- need to access very high-resolution data, which are mainly available as commercial services;
- gap filled time series of high-resolution EO data;
- detection of emergence and harvest data;
- even though the main driver for AMS is the cost savings, there are no real calculations of how much it will be saved - the cost of IACS increased over the years and AMS for sure will not decrease that cost (how to calculate?);
- calculation of how much use of the European Data and Information Access Services (DIAS) can save total cost;
- list of available and future Copernicus core services and their possible usage in AMS;
- data and predictions of the occurrence of voles and the system of protection against them;
- data and procedures for the protection of animals during haymaking;
- data and procedures for predicting grasshopper invasion;

- historical data for the needs of multitemporal studies;
- data for the creation of 4D and 5D data models for agricultural production;
- it is important to re-use previous financing and previously developed platforms from H2020 projects as building blocks for Destination Earth;
- in order to reach the Sustainable Development Goals and European Green Deal goals, it is necessary to build public private partnership;
- there is a need for additional multi-actor research across domains (agriculture, food, biodiversity, space, IT), which will help to use the full potential of Earth observation for agriculture.

Results and discussion

The white paper was the first presentation of the EO4Agri vision about the role of EO in agriculture. It was recognised that the increasing economic, social, and environmental needs of agriculture pose many challenges for upcoming years. This topic is closely related to the strategies of the UN SDGs and the European Green Deal on sustainability. The white paper stresses the importance of knowledge management for agriculture to help to solve new challenges in the agriculture sector. The white paper focuses on the definition of key problems, analysis data gaps, delivery platforms, analytical platforms, and final recommendations for future policies and financing. The document serves as an input for the Policy Roadmap and the Strategic Research Agenda.

As two main final results are:

- Policy roadmap - set of recommendations towards CAP reform;
- Strategic Research Agenda - list of priorities for future research activities in different programmes and initiatives.

Policy roadmap

The policy roadmap prepared set of recommendation for future update of Common Agriculture Policies to benefit better from Earth observation technologies:

- The current frequency of Sentinel data is sufficient, but the spatial resolution would still be preferred to be at 5 or even 1 meter;
- to prepare a horizontal action plan how to deal with current issues (small parcels, complex subsidy system with few monitorable eligibility criteria, doubts about the future audits approach, lack of skills, funding, infrastructure, etc.);
- to conduct a survey about usage of developed tools of International projects: it is still not clear how PA's are planning to test all the tools as well as Free and Open Source Software (FOSS), that are/will be developed through those international projects;
- to organise a cycle of webinars about existing and future Copernicus Core service products: it is a need of learning how these products could be used for CAP (27 PA's out of 29 in 2020);
- EC should be the main provider of all the needed algorithms for AMS (crop type, grass mowing detection, etc.);
- production of centralized vegetation indices and provision of "Signals as a Services" (EEA and VA Industry). EEA has placed a contract for systematic production from Sentinel-2 of "High Resolution Vegetation Phenology & Productivity" (HR VPP) products (NDVI, LAI, FAPAR, seasonal trajectories, productivity parameters) for access via the CLMS; geographic coverage is EEA39. DG-AGRI, JRC and EEA should jointly assess the suitability of HR VVP and the possibility to steer production and data dissemination for CAP Monitoring purposes;
- it should be made easy for Value-added Industry (e.g., Data Cube Service Providers) to integrate with the CLMS for implementing parcel-based signal and marker services based on HR VPP, if adequate;
- necessity to define the minimum scope of CbM as a legal part of the Area Monitoring System (AMS): list of minimum requirements (measures, criteria) for setting CbM should be prepared. Current performance output indicators are not adapted to be moved to the new AMS. EU MS are overloaded with different requirements in different countries, which are not designed for direct monitoring with EO data, e.g., permanent crops rows mowing, etc., therefore there is an urgent need of simplification and reduction of their number;

- developing a good practice knowledge database of controlling different requirements. The EC could take over this responsibility. The knowledge database should be shared among the EU MS;
- the EC should include a reference in its respective AMS regulation about conditionality: instructions on using satellite data related to conditionality (replacing cross-compliance) and remote sensing requirements, e.g., control of spreading manure; fallow; burning, etc;
- an overall EC leadership on conditionality (cross-compliance) and agri-environmental schemes is still missing;
- more suitable EU legislation for using of Copernicus Sentinels: higher threshold of minimum eligible parcel for support (when CbM applies); simplification of Greening, Agro-environmental and other CAP non-monitorable requirements (e.g., specific plants for crop diversification, two different crops for catch crops);
- it is necessary to update the respective EC Regulations to lower the requirements for MS for Monitoring approach (e.g., raise level of traffic light threshold (EUR 50/250);
- it is necessary to improve EC standards for "GeoTag" tools, aiming to increase harmonization among different countries;
- geo-tagged photos & in-situ data: the initiatives by GSA and DG-AGRI for developing tools (e.g., FAST) for helping farmers to collect and communicate in-situ information with the Paying Agencies are considered important and shall be pursued towards "de-facto" standard practices;
- "Planet Scope time-stacks data" are generated for parcels which cannot be monitored by Sentinel due to geometric resolution. There shall be guidelines on how to use VHR EO data and the EC shall continue to support demonstration projects and communicate lessons learnt to the Paying Agency's community. Furthermore, the information shall be made widely available on how Paying Agency systems can integrate with VHR EO data dissemination services (via API);
- it is necessary to educate the general public and farmers as end users of EO to increase the proactive use of products and data from EO;
- centralised CARD4L production (DIAS): JRC (via ESA contract mechanisms) has been tasking the four industrial DIAS's to demonstrate large-scale production of Sentinel-1 backscatter and coherence as well as Sentinel-2 L2A;
- DIAS individually reported to be ready as presented to Expert Group for Direct Payments (EGDP) during the info event on 24 January 2020;
- follow up by the EC DG AGRI and JRC with Paying Agencies in promoting these DIAS production capabilities further and of a higher technical level.

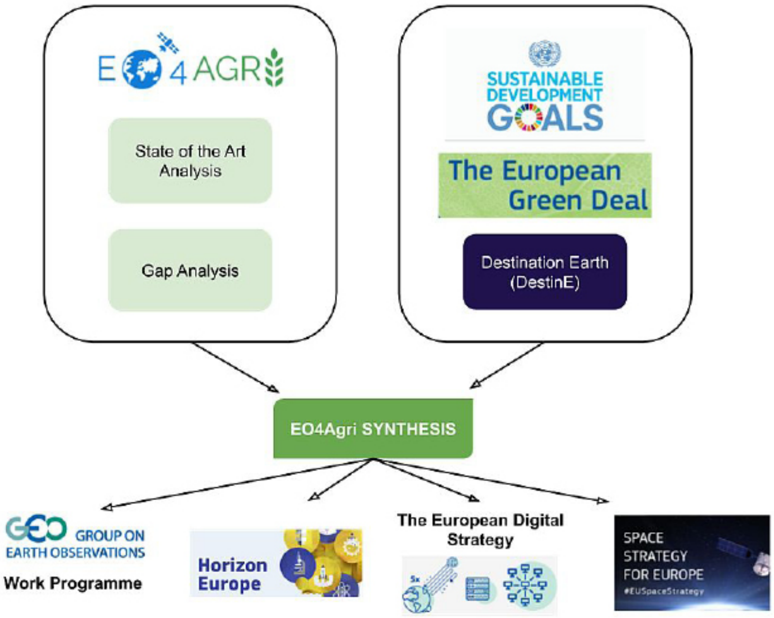
Strategic Research Agenda

The EO4Agri Strategic Research Agenda (SRA) (Šafář et al., 2020). is a set of recommendations for future research activities in the area of Earth observation for agriculture. It is one of the key deliverables in EO4Agri and there are two objectives of this deliverable:

- To prepare an input for the European Commission, European Space Agency and Group on Earth Observations (GEO) how to build future research and innovation activities in this domain;
- to help the research and innovation community to discover potential topics for their future research in the frame of the current financial mechanisms and initiatives.

The EO4Agri SRA is based on a synthesis of the current requirements coming from political and research frameworks, and gap and technological analysis provided by EO4Agri. The EO4Agri SRA is a list of recommendations for future activities in the GEO, Horizon Europe) and the Digital Europe programmes. It is not a revision of these programmes, but additional recommendations or tasks, which are important for future revisions of these programmes. Most of the gaps identified by EO4Agri are well addressed by the current programmes. In some cases, revisions of these programmes will be inevitable.

Figure 5 depicts the approach for defining the SRA.



Source: Šafář et al., 2020.

Figure 5: Basic schema of the SRA definition approach.

Final recommendations

On the basis of previous analysis, the EO4Agri prepared three sets of recommendations, for future better utilisation of Earth Observation Technologies in Agriculture. It could be divided as:

- Technological recommendations
- Future scientific priorities
- Organisation recommendations

Technology recommendations

Overall, a wide range of agricultural applications supported by Copernicus data and services already exist including a long list of success stories. However, there is still a large potential for improvements. Concrete short term and long term actions were identified including the agenda for future research (Kolitzus, 2020).

Technical Aspects

For many applications in agriculture the spatial and temporal resolutions of the Sentinel missions are not sufficient, and the upcoming open satellite missions will not close this gap entirely. Data fusion with commercial data providers seems absolutely necessary and two potential Copernicus products with huge added value are possible:

- Provision of a gap-filled time series of vegetational and biophysical parameters (with S-1/S-2/S-3 and commercial VHR/HHR data) going towards daily observation;
- provision of super-resolution approaches to increase the spatial resolution of the Sentinel missions using commercial VHR/HHR data as calibration and validation points.

A major benefit would also be to integrate field polygons as open government data and directly allow analysis on field level and lifting the burden on field parcel delineation. On top, the integration of various other in-situ data is advised:

- agricultural in-situ data like JECAM (Joint Experiment for Crop Assessment and Monitoring). etc. wherever possible;
- option to integrate your own data:
- (agricultural) machinery data, support for agro-xml
- drone data
- IoT
- farm management tools such as FaST

As a consequence, the support and further development of various agriculture for research (ARD) initiatives is recommended in the short term. In long-term, a closer collaboration between open EO data service providers and commercial providers are recommended:

- Further finance and support such as Data Cube;
- consider sensor alignment with commercial

service providers already in the design phase of new sensors;

- invest in research dedicated to data fusion techniques and cross-sensor calibration
- close collaboration with existing and possible future providers to ensure compatibility in the long run;
- for new projects it could be suggest and or made mandatory to contribute and share available data (following standard procedures and protocols) with one or several of the available initiatives (DIAS, Euro Data Cube);
- furthermore, newly developed methods and applications in the field of precision agriculture and overall in the domain of remote sensing are often only trained and tested in small areas of interest and their accuracies are often much lower or highly uncertain when applied in other geographic regions. The lack of standardized and designated testing areas across the globe and the provision of reference datasets (including ground truth) would facilitate the comparability of existing methods and the assessment of their accuracies. Especially the provision of parcel/field level might will drastically improve usability and enable new applications.

Satellite mission

The Copernicus Sentinel fleet is offering unprecedented data and is the most ambitious endeavour in the domain of land monitoring so far. In the context of agricultural monitoring, a couple of aspects are noteworthy.

Given that for agriculture the natural unit is a field/parcel, the spatial resolution is dictated by this aspect. Field sizes vary largely over the globe of course, but overall, spatial resolution is not satisfactory for a large number of applications, a spatial resolution between 1 and 5 meters is desirable.

In contrast to the monitoring of other landscapes and landscape objects, agriculture is highly variable (more variable than forest) and due to crop rotation or other management practices, it might be a different phenology every other year.

In addition to that, during a single growing season, various types of plants will grow and the overall phenological fluctuation is larger than for other land cover and land use. On top of that, the window of opportunity for precision farming is very often limited to a narrow phenological window (1 or 2 weeks) where the decision-making capabilities of Copernicus are needed. The required temporal resolution for many agricultural applications is therefore very high as well.

The existing Copernicus missions already cover many of the identified requirements of the agriculture domain. Additionally, the foreseen evolution of the existing Copernicus missions and upcoming candidate missions further fulfil the requirements. However, some conclusions can be made for the evolving mission specifications of the Sentinel programme in the long term, especially with regards to spatial resolution (~5m) and revisit times (1-3 days). A number of gaps not covered were identified, in particular concerning VHR optical data, HHR optical data and high-resolution X-band SAR data, all of which are available from commercial providers. With respect to microwave and thermal data (i.e., LSTM and CIMS), further developments may inform future more detailed data requirements on these topic.

ICT aspects

The Copernicus satellite observation capacities are operational and are routinely providing high-cadence monitoring data. In addition to the Copernicus open data hub, five DIAS are operationally providing data access as well as computational resources. However, it must be noted that no certainty about sustainability of DIAS future operations beyond 2021 exists.

The continuation of at least one of the DIAS providers is highly recommended to facilitate the use of Copernicus data and services. The functionality to process and provide higher pre-processing level data and (C)ARD have been demonstrated and is advised to continue.

Overall, the interoperability with other satellite data as well as in-situ data from all parts of the agricultural value chain still has room for improvements. This includes data such as direct meteorological data (forecast as well as historical data), climatic data or other machinery or ground-based soil data. Activities such as the Euro Data Cube and the Agricultural Virtual Laboratory are further follow-up on this approach.

Future scientific priorities

On the basis of the analysis of stakeholder needs a set of future scientific priorities were defined. These priorities could help to policy makers prepare new research programmes and scientific communities to identify new research directions.

The priorities are divided into four thematic groups:

- Biodiversity
  - Analysis of historical development and understanding of interrelation between changes in biodiversity and climate. There exists historical data from EO with relatively high frequency for more than 40 years. For such periods are also available detailed climatic data. Using Artificial Intelligence on this historical data can help us to improve understanding of biodiversity decline;
  - Earth onservation data will be ideal source for real time monitoring in large scale and early warning.
- Sustainable farming
  - There is necessary research in different methods of monitoring and data fusion of Satellite data, with IoT data and also integration of climatic data and also existing terrestrial data. It is also important to include commercial very high resolution data, aerial and UAW data. There will be necessary cost benefit analysis and selection of best monitoring methods. The research has cover selection of bands, analysis of time series, data fusion;
  - future precision farming has to be focused on reducing the use of usage chemicals, but guarantee production. So, there is necessary research in nutrition and crop protection, but also in methods of seeding or tillage. Research needs to compare the potential of different approaches to utilisation of Precision Agriculture. For example, now in fertilisation are used two different strategies the Yield-oriented strategy is based on the principle of a higher requirement for nitrogen nutrient to cover a higher level of expected crop yield, which is spatially distributed by the yield productivity zones. The second strategy homogenization is based on the concept of agronomic and nutritional practice developed since the 1980´s, when nitrogen is considered a yield-limiting factor and low-yielded areas are supported by higher doses of N. There exist number of similar agronomic problems, for example tillage and non-tillage, etc. and there is necessary provide comparison of all such possibilities and select, such which will help fulfil requirements of Green deal and guarantee sustainability and profitability of agriculture;
  - Current Precision Agriculture is mainly focused on site specific operations (Where). Our analysis demonstrates that for future we need much more consider right timing of operation (When), based on analysis of EO and climatic data and also on selection of rights species, chemicals, operations (What);
  - combining satellite data and climatic data from different zones to build strategy for Smart Farming;
  - build new crop growth scenarios under different weather events. Plan optimal timing for different field operations;
  - prediction of disease susceptibility of crop using the temporal crop dynamics from Earth onservation data;
  - accurate monitoring of crop phenology;
  - assessment of hydrological flows through a combination of field observations and output from satellite image analysis workflows;
  - augmenting weather and climate monitoring through the use of affordable in-situ weather sensors and remote sensed weather estimates;
  - usage of satellites with Very High Resolution.
- Innovation governance
  - The research has to be focused, how EO can support forming regional, national and local policies. The focus will be on analysis of agriculture production, biodiversity and provide impact assessment of governmental decisions;
  - to be able to fully use the potential of Environmental Observation it is a necessary guarantee in global scale easy discoverability of data. Metadata is necessary to include all history of processing (provenance). There is need for supporting better interoperability of Earth onservation data. The recommendation is to organise Coordination and Support Action to support FAIR and Interoperability among existing platforms;
  - the FAIR principles, metadata and interoperability need to be topic;

- effective Agricultural Knowledge and Innovation Systems (AKIS) are key drivers to enhance co-creation and thus speed up innovation and the take-up of results needed to achieve the Green Deal objectives and targets. There is now a large investment into Digital Innovation Hubs (SmartAgriHubs). The model of Digital Innovation Hubs has to be implemented to increase knowledge and awareness about Earth observation methods. The existing infrastructures (DIAS, EUXDAT, EOSC, etc.).

◦ Enabling technologies

- Object recognition from satellite and other images. From in situ cameras (on board cameras on Agriculture machinery) strong focus will be on embedding of AI directly into on board computers with possibility to detect objects directly on board for example to detect on the fly pest or weeds. This will be also closely related to robotics system. Similar solutions can be also applied on UAV platforms;
- analysis of time series. This time series of data coming from IoT technologies, data from satellite and climatic data and their combination will be probably key technologies for building future scenarios Taking into account, that there exist historical satellite and climatic data for more than 40 years, this offers large possibilities for training AI tools on historical data and then use these technologies for building of future scenarios. This could be used in Precision Agriculture, biodiversity, climatic changes mitigation, etc.;
- trust and provenance of data - it seems that these are two independent issues, but they are linked. When we will share data, which are not open we need to protect this data, so we need tools for tracing data owners, but we also need to make evidence of any operation provided on data and in the end, we need to store this information in metadata. Such functionality could be probably solved by tools for data security in combination with technologies like blockchain, which will give evidence about using data resources and their combination and analysis. This could be done by combination metadata with blockchain technologies;
- development and integration of different data like data from IoT technologies and citizens science;
- advanced 2/3/4 D visualisation methods, virtual reality;
- how to guarantee storage, easy discovery and fast access extremely large data sets;
- HPC computing including parallelization of code;
- development of new hyperspectral systems with high resolution;
- increase resolution of new systems;
- analysis of hyperspectral data including new indexes;
- temporal analysis of data;
- data fusion with other data sources;
- better utilisation of radar and lidar data.

Organisational recommendations

The last set of recommendations was focused on organisational aspects, what has to be done to guarantee better utilisation of EO data in the agriculture segment. We defined ten key recommendations:

- Organise regular workshops and conferences of all interested stakeholders. These workshops and conferences have to lead to the exchange of information, but they also need to educate all stakeholders about new methods;
- support cooperation of all players from the public and private sectors to fulfil the European Green Deal, Destination Earth and the UN SDGs. It will also invite the food industry, machinery, chemical industry, IT industry, financing organizations to build a common environment;
- support new common multi-actor research involving both EO and agricul-ture/ agronomy experts to develop new methods that guarantee food security and agriculture sustainability;
- support the farming sector with open data, including Copernicus and other EO data. This will require additional investments. Put into the practice FAIR principles;
- developed new metadata models and strategy for sharing all data across Agriculture;
- reuse previous solution. On the one side, continue with the development of new

technologies and EO methods to build future Digital Twins. On the other side, there exists a large potential of existing technologies recently developed, which potential is not fully exploited. It's necessary to prepare an overview of existing technologies and discussion among the teams on how to make solutions interoperable and how to re-use existing solutions;

- finance a large number of smaller independent projects for technical development. This can bring new ideas in the short term;
- support standardization efforts and use of existing standards. This needs to be done in cooperation with existing standardization bodies including OGC, ISO, and W3C;
- spport large scale coordination actions, which will improve cooperation among different projects, initiatives, and standardization organizations. This needs to sup-port both standardisation and FAIR principles;
- there exist several technical problems, but the biggest problem will be at the level of legislation and financing. It will require a reform of the CAP and also build effective strategies. This cannot be done only on a political level, but it will require communication of politicians with technical experts and researchers to define a successful strategy. For this purpose, it is necessary to establish a forum, where all these players will meet. A new strategy has to be prepared based on expert opinions and scientific results.

Conclusion

Satellite data is an important source of information for future agriculture. The aim of the research, which is emphasized in the article, was to find out the real state of use of EO data for all players who enter the food production process from manufacturers of agricultural machinery, fertilizers, navigation systems through EO experts, farmers and food production complex.

The paper demonstrates how the EO aspect in support of agriculture should improve. There is a clear need for new data, better spatial and temporal resolutions, new bands, and more dense data. The research, however, revealed that farmers' willingness to pay for such services are limited. This is one of the limiting factors for the future development of EO services in the agriculture domain.

The need for in-situ data is another important issue, helping users to use remote sensing data optimally. The process of deriving useful information from satellite data that can help farmers to make precise decisions must be supported. One of the conclusions on how to help make more intensive use of EO data is the idea the DIAS instances will be self-financed, which could lead to the fact that some of them will be not operational after the end of their contracts.

On the one hand, there are large investments from the public to private to build new solutions and delivery platforms. On the other hand, agriculture is highly fragmented with enormous amounts of players in different sectors (e.g., machinery, insurance, fertiliser producers). Access to knowledge is limited and the current investments are not efficiently utilised. There is an urgent need to verify the investments for all public and private partners and get a deep understanding of the return of investment for all participants as well as verification of climate change and/or environmental positive or negative effects. A new understanding of precision farming services can not only increase production but produce products of higher quality, have fewer negative influences on the environment, and also reduce different environmental risks.

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