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Adoption of Precision Agriculture across Europe: a case study on remote sensing

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Abstract

Studying the adoption of Precision Agriculture (PA) is important to identify future challenges and research questions. Currently, there is no mechanism to monitor and compare PA adoption at the European level. This paper addressed this issue and proposed a monitoring mechanism based on remote sensing adoption as a case study. A study was set up in six EU countries (France, Germany, Hungary, Italy, Slovakia, and Spain). More than 170 stakeholders were interviewed. While the adoption rates varied between countries and usages, the results confirmed an increasing application of remote sensing in agriculture.

Keywords: Drones, Satellites, UAV, Value chain

Introduction

Future food security necessitates the need to deploy the appropriate Precision Agriculture (PA) technologies. However, their success depends on the adoption level and the types of adopted technologies (El Bilali et al., 2021). There is no database on PA adoption in Europe, but several studies have been done to evaluate the factors influencing adoption rates. Barnes et al. (2019) did a cross-regional study in five European countries by using interview methods with 971 producers. The study explored the adoption of variable rate nitrogen (N) technologies and machine guidance by estimating the differences between adoption and non-adoption.

In their work, Blasch et al. (2021) focused on exploring the drivers and barriers that influenced the adoption rates of the variable rate application (VRA) of N in Lower Austria. In their survey, 242 producers participated via questionnaires. The study

concluded that financial support and promotion of networking and knowledge-sharing among producers were crucial factors influencing the adoption of VRA. After analyzing 474 online survey responses, Giua et al. (2022) concluded that among other factors, individual intentions, resources, and existing formal relations along the supply chain influenced the adoption process of PA.

These previous studies focused on producers and may present potential bias regarding the composition of the panel. Either the sampling was non-random (Barnes et al., 2019), or was not explained (Blasch et al., 2021), or an online survey was used (Giua et al., 2022) that often has a selection bias (Greenacre, 2016). A couple of studies were able to measure farm-level adoption rates of specific PA technologies and claimed to have representative samples (Danmarks Statistik, 2022; Groher et al., 2020). However, these studies were done at a country level and did not represent a general picture of Europe.

To rectify this, this work was designed and implemented to provide an overview of the current status and future potentials of remote sensing usage in agriculture, in six different European countries. Following the methodology proposed by Lachia et al. (2019), the stakeholders of the remote sensing value chain were identified and representatives from each category were interviewed. The main novelty lies in introducing the concept of a unified PA-related value chain that involves all important stakeholders to better understand technological uptake and use within a country.

Materials and methods

General Approach

The remote sensing value chain was chosen as a focus of this approach for three main reasons: i) it has a long tradition in agriculture (>20 years); ii) the involved technologies are changing fast, especially in recent years with the arrival of unmanned aerial vehicles (UAVs) and new satellite constellations (Sentinel-2, Planet, etc.); and iii) the value chain was assumed to be simpler than for other PA technologies.

The methodology implemented was organized around a scientific committee at the European level and local committees in each country studied (Figure 1). The role of the scientific committee was to define the scope of the study and to design a common survey methodology. It included all scientific partners involved in the project. The role of the local committees was to carry out the studies in each country based on their knowledge of local agriculture and local partners. Each local committee was composed of members from a university in the country. Local committees were in charge of evaluating the adoption of remote sensing in agriculture by interviewing the different stakeholders. Regular discussions were done between representatives of the scientific committee and each local committee to get feedback and to ensure global coherence.

Countries studied

The study was carried out in six countries chosen to be as representative as possible of the diversity of types of agriculture and technological maturity of European countries: i) Slovakia and Hungary represented Eastern European countries, ii) Spain and Italy represented Mediterranean countries, and iii) Germany and France represented North-Western European countries. Table 1 gives a general overview of the differences in land surfaces of each country, their agriculture use, and typical sizes of production systems.

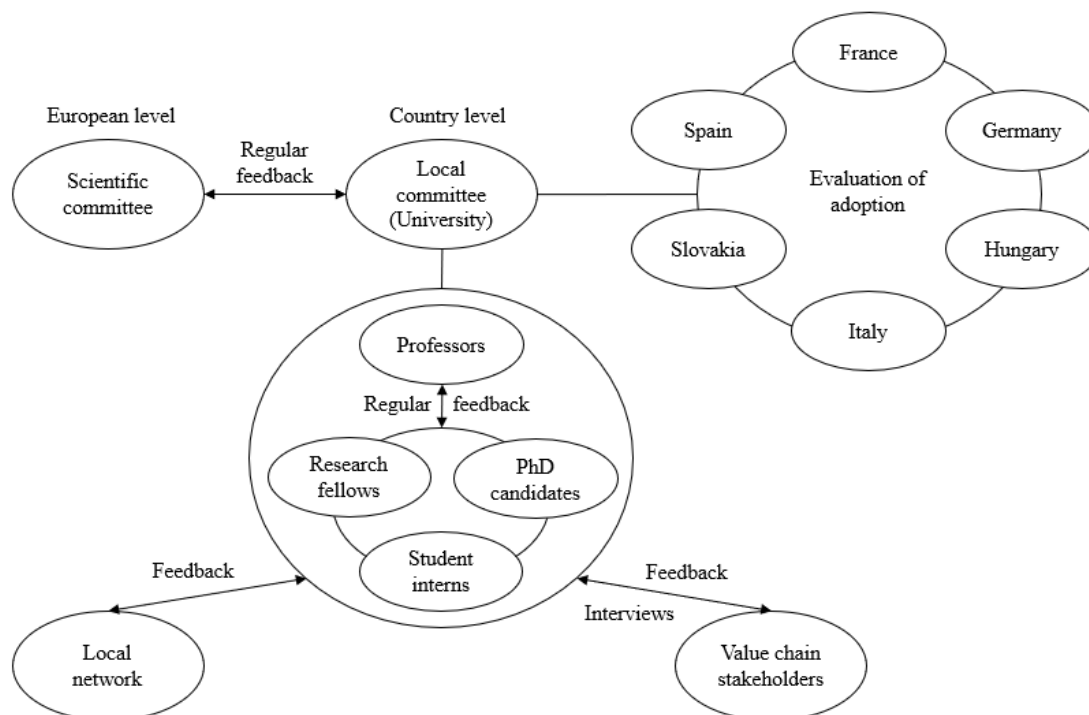


Figure 1. Methodology of the pan-European observatory showing the academic oversight at local and European levels and the focus on the value-chain as well as the end-users.

Study of adoption

As a first step, the local remote sensing market in agriculture was mapped for each country to identify the main stakeholders involved in the value chain. The first version of this mapping was made based on the literature review and academic knowledge of local stakeholders. It was iteratively updated after each interview with stakeholders that mentioned their competitors, partners, suppliers, or customers. Over the course of the iterations, the description of the value chain evolved and then stabilised. When it was stabilised, it was considered representative of the sector. This mapping was used to define the types of stakeholders who played similar roles in the value chain. In the second step, interviews were conducted in each country with stakeholders of each type. In total, more than 170 stakeholders were interviewed. The methods of the interview included direct and online interviews and email questionnaires. Qualitative and quantitative data were collected.

Table 1. Organisation of land use per country.

Country	Land area, (1000 km ²)	Agricultural land, % of land area (as of 2020)	Arable land, % of land area (as of 2020)	Permanent cropland, % of land area (as of 2020)	Number of agriculture holdings (as of 2010)	Mean area per holding, (ha) (as of 2010)
France	547.56	52.1	32.8	1.9	489 980	55.0
Germany	349.39	47.5	33.4	0.6	299 100	55.8
Hungary	91.26	53.7	44.0	1.7	576 690	8.0
Italy	295.72	44.0	23.1	8.2	1 620 880	7.9
Slovakia	48.08	39.2	28.0	0.4	24 460	77.5
Spain	499.56	52.3	23.3	10.0	989 800	24.0

Source: (Eurostat 2022; The World Bank 2022)

Data analysis was performed for each country, and the results were transformed into qualitative descriptions and quantitative figures. The main focus was put on: i) main remote sensing platforms; ii) the main kind of remotely sensed crops; iii) main agronomic applications of remote sensing; iv) estimation of remotely sensed agricultural area (if available); and v) identification of factors and barriers to adoption.

Results and Discussion

The results of the interviews showed that the value chain and the types of stakeholders involved in remote sensing in agriculture were the same in the six countries studied (Fig. 2). The first type of stakeholders were companies developing sensors and vendors for image acquisition. The second type were companies managing the logistics of image acquisition and pre-processing (e.g. geometric and radiometric corrections). In these two first steps of the value chain, companies were often distinct for UAVs and satellite-based services. The third type of stakeholder were companies (or in some cases universities) providing agronomic services based on remote sensing images. The fourth type corresponded to the distribution of services to end users based on this advice. In rare cases, the distribution was done directly by service providers. Finally, end users were the last type of stakeholders in this value chain. At the field level, they were mainly producers. At the regional scale, they were mainly public and governmental entities.

Main remote sensing platforms

Satellites and UAVs were the two main platforms mentioned in the interviews while aircraft imagery was regarded as a less common platform. The arrival of Sentinel-2 of the Copernicus European program was mentioned in many interviews as a game changer in the market of remote sensing technologies. The introduction of this satellite mission and the availability of free images with a high temporal resolution seemed to have led to the emergence of new stakeholders and services. It divided the evolution of this sector into 'before' and 'after'. Other satellites (Planet, Landsat) were mentioned, in particular, in Spain. All the companies interviewed in this country mentioned Planet Labs as the main provider of image data. Globally, 5 - 6 major stakeholders were identified as providers of satellite images for agriculture at the EU level.

The UAVs were mentioned to be used by private companies providing services and creating maps on demand. Most of these companies were not specialised in agriculture and were just considering this sector as an additional market. The market of UAVs can be considered as a service provider business that competes on a local level.

As already noted, helicopters and aircraft were rarely mentioned in the interviews. The main obstacle to this technology seemed to be the high associated cost but it appeared to be appropriate for some specific cases. In Spain and France, helicopters and aircraft were used by a small number of companies for the monitoring of large agricultural areas with multiple clients within the target area. In Germany, France, Italy, and Slovakia, aerial imagery was also used by the government or local authorities to map the territory or evaluate subsidies. Corresponding images were generally available for free and in an open-access format.

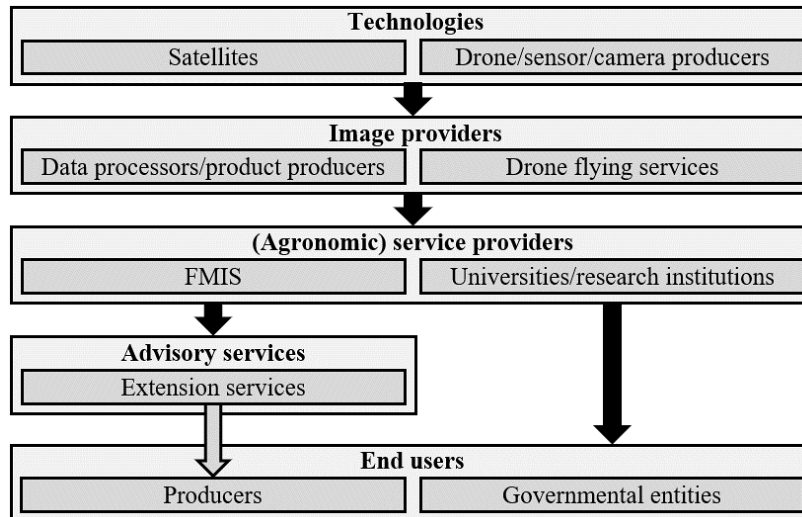


Figure 2. A schematic indicating connections and flows with the agricultural remote sensing value chain (FMIS = Farm Management Information Systems/Services).

Main kind of crops for which remote sensing is applied

Remote sensing can be applied to any crop but it was highly related to the organization of agriculture in each country. Based on the study results, a lot of effort and research were done by companies and universities to adjust remote services to different types of local crops. The main arable crops mentioned by the interviewees were wheat, barley, corn, triticale, and rapeseed. However, vineyards were also highlighted. For Hungary, orchards were especially mentioned. In addition to the main arable crops, beans and some specialty crops, such as walnuts and potatoes, were discussed by the stakeholders from Slovakia. For Germany, as well as the abovementioned arable crops and vineyards, crops such as strawberries, garlic, and perennial fruits were also identified. High-value crops appeared to be of bigger interest for remote sensing applications.

Main agronomic applications of remote sensing technologies in agriculture

Several end uses of remote sensing were discussed by the respondents of the interviews. Many of them were common for the countries studied; however, due to the differences in the organisation of agriculture, specificities between these countries existed. Remote sensing was often used more for general observation tasks, such as measuring field boundaries or examining whether any obstacles (e.g. stones, wild animals, animal and bird nests, etc.) existed. When it came specifically to PA, vegetation indices (VIs) were the most widely used form of remote sensing technologies. In particular, prescription maps for N fertilization from VI data appeared to be among their main uses. VRA was noted as gaining more attention because of stricter regulations that were introduced with the Farm To Fork Strategy. With an increasing burden on producers to reduce their use of chemicals, producers tended to become more interested in the PA technologies that could help them manage their farms in a more environmentally friendly way and, consequently, decrease the risk of being exempted from the subsidies.

Other types of applications were found at the early stages of adoption in other countries. For example, yield prediction, disease monitoring, and in-field/in-season variability mapping were all getting attention in Germany. However, while the stakeholders in Germany mentioned irrigation as a developing topic for which remote sensing would be used in the coming years, in Spain the use of remote sensing to generate irrigation maps

was already common for corn production and in some wineries. In the latter, they also used remote sensing for selective harvesting. Several specific uses were observed in France, such as using remote sensing for scientific experiments related to phenotyping. The use of remote sensing in vineyards for field observation and sampling was reported as being already in use in France. However, the actual uses were very specific and personalised. Another popular field for remote sensing was weed detection. In both Spain and Germany, but not elsewhere, weed survey maps were mentioned as becoming very popular. The main use of satellite data in Slovakia still seemed to be for the production of free data by public institutions to observe general production patterns. In Hungary, the big companies used satellite data within the software that they distributed (which was created by foreign companies) for either background effects or to provide the measuring of the fields, the processing of the data and identification of the special parts, and the creation of maps.

Estimation of remotely sensed agricultural area

Except for the country-level study presented by Danmarks Statistik (2022), the literature research done within this work did not find any other existing studies that provided a clear understanding of the agricultural area that was covered by, and that used, remote sensing services at the EU level. A novelty of the approach used here was the ability to achieve this based on the obtained information from the interviews and some local databases. The research observations showed that the agricultural area covered by remote sensing for PA purposes varied between countries but was still overall at a quite low level. Moreover, in some cases, it had decreased over the last few years. For example, in France, the area of agricultural land using remote sensing dropped from ~1 100 000 ha in 2016 to ~905 000 ha in 2020. However, the percentage of the agricultural area that was remotely sensed in France was approximately 3.2 %.

The situation was different for Spain where the area covered was ~5 000 000 ha or ~20 % of the total agricultural area but the area being imaged appeared to be growing. However, an important aspect related to this remotely sensed area (which remains unknown) was that it was being leveraged in FMIS for administrative uses, sometimes without any agronomic advice. Within this, ~90 % of the imagery was from satellite services in extensive, arable systems. But, for non-arable crops, like perennial fruit and olive trees and vineyards, UAVs were dominant, leaving the satellite systems with less than 5 % of the area imaged. In contrast, in Germany, the whole remote sensing market regardless of crop type was dominated by satellite imagery (~80 %). However, the agricultural area covered by remote sensing services was lower (below 10 %).

In other countries, there was an even less percentage of the remotely covered area. In Slovakia, only 30 000 - 50 000 ha (between 1.5 % and 2.6 % of the total agricultural area) were estimated to be remotely sensed in 2020, whereas in Hungary the estimation was even more difficult to get, due to variable and uncertain feedback from the interviews. However, based on the obtained data, this indicator was ~5 % of the total agricultural area. One of the research questions in Italy was directed toward collecting quantitative data from the respondents about the actual percentage of agricultural land that used remote sensing. The highest number of replies (~40 %) stated that only between 5 % and 8 % of the agricultural land in Italy was using such maps. This gave a reason to assume that the remotely sensed area in Italy was also less than 10 %.

It is worth noting that the level of uncertainty associated with these estimations is relatively high. These results may be considered as a first estimation for the six countries. Further research is needed to make more precise estimations.

Identification of factors and obstacles to adoption

The main findings from the study from a pan-European perspective were summarised in the SWOT analysis (Table 2) **Erreur ! Source du renvoi introuvable.** However, some national effects were present. In France, regulations, and traceability played a more important role in the adoption of remote sensing technologies. In Germany, these were also important but an additional factor that might contribute to adoption was that many small companies and start-ups were trying new things and increasing their efforts toward research in remote sensing. In addition to that, the Federal State was increasing its support for the development and usage of remote sensing applications. In Spain, a high climate risk played a factor in pushing the adoption of these technologies, while in Slovakia the development of remote sensing was being promoted as an effort to attract more young people into the agri-environmental sciences. In Italy, public subsidies promoted the acquisition by even small farms of advanced equipment, ready for implementation of remotely sensed data.

Table 2. A Strengths-Weaknesses-Opportunities-Threats (SWOT) analysis of the adoption of remote sensing technologies in European agriculture.

Strengths	Weaknesses
<u>Socio-economic:</u> A long tradition of remote sensing in agriculture Increasing interest Public awareness about sustainability problems pushes the adoption of PA <u>Technological:</u> Gaining a lot of information Intensifying agricultural research	<u>Socio-economic:</u> Agriculture is not the main focus of remote sensing Producers' needs are not considered A lack of contact between the industry and producers No economic benefit for producers Education gap <u>Technological:</u> Remote sensing remains very academic Obsolete farm machinery
Opportunities	Threats
<u>Socio-economic:</u> Open-mind of younger generations The motivation of producers to have an easy tool A positive general trend of development Public subsidies <u>Logistics:</u> Taking the drone out of the producer's hands A growing number of service companies Facilitation of producer's management decisions Local contacts through farmer associations <u>Legislative:</u> EU regulations (promoting VRA) <u>Technological:</u> Development of index-based insurance Development of hardware and software platforms The appearance of online FMIS to monitor crops	<u>Socio-economic:</u> Producers' unwillingness to share the data/ learn new skills Disappointment of producers/ High expectations A lack of mechanisms to create trust Producers fear having another complicated machine in their fleet (e.g. an UAV) <u>Technological:</u> Focus on the wrong technologies, which are not of real interest to producers <u>Logistics:</u> Ignorance of small producers by large enterprises <u>Legislative:</u> Changing regulations for UAV

Conclusion

This study presented a method of evaluation of PA technologies adoption focusing on remote sensing services in six EU countries. By including local networks and contact and, at the same time, following a coherent approach and supporting a regular feedback procedure, the research resulted in an effective way that can be applied for further research on this topic. The outcomes of the work highlighted that differences in technology perception and usage existed among countries. Many factors influenced the adoption of remote sensing technologies depending on the country's agronomic practices. The study observed an increasing interest in the application of remote sensing technologies for PA and their impact on future market developments.

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