REPORT ON AGRICULTURE USER NEEDS AND REQUIREMENTS

OUTCOME OF THE EUSPA USER CONSULTATION PLATFORM

GALILEO EGNOS copernicus

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01 INTRODUCTION AND CONTEXT OF THE REPORT

Increased and more sustainable agricultural production, being central in addressing a number of important societal and economic challenges (e.g. projected global population growth, increased food demand, higher caloric intake of an increasing middle class), strongly relies on GNSS-enabled solutions in a number of applications. GNSS user requirements, strongly interlinked with the growing and evolving market trends, are driven by

- The need for increased profitability of agricultural operations, achieved primarily through machine utilisation optimisation, acquisition of greater quantities of reliable site-specific information and optimisation of input costs (fertilisers, fuel, labour)
- The need to introduce solutions applicable (in terms of cost-benefits) to small and medium-sized farms, whilst overcoming socio-cultural barriers (lack of education, awareness, equipment ease-of-use, etc.)
- The need to comply with policy considerations related to the disbursement of agricultural subsidies and other regulatory aspects for environmentally friendly agricultural practices
- Significant improvements in High-Accuracy solutions (e.g. multi-constellation, multi-frequency, Galileo High Accuracy Service (HAS), coupled with increased availability of low-cost equipment (e.g. EGNOS-enabled devices and more affordable GNSS RTK solutions)
- Combination of GNSS with other complementary technologies such as Remote Sensing, proximal sensors, IoT and robotics, within integrated farm management solutions.

In this framework, E-GNSS solutions could hold a significant role in the evolution of the utilisation of GNSS by farmers across the various application domains.

The User Consultation Platform (UCP) is a yearly organised forum for interaction between end users, user associations and representatives of the value chain, such as receiver and chipset manufacturers, application developers and the organisations and institutions dealing, directly and indirectly, with Galileo and EGNOS. In this context, the objective of this document is to constitute a reference for the precision agriculture community by collecting and analysing the most up-to-date GNSS user needs and requirements in the agriculture market segment. The document should serve as a key input to the UPC so that main included outcomes can be validated and subsequently updated.

The analysis is aimed to provide the EUSPA with a clear and up-to-date view of the current and potential future user needs in order to:

- Reflect the latest trends and developments and anticipate impact on future E-GNSS, therefore, preparing the future EGNSS (G2G);
- Ensure the E-GNSS market uptake.
- Finally, as the analysis will be publicly available, it will serve also as a reference for users and industry supporting the planning and decision-making activities for what concerns the use of location technologies.

E-GNSS SOLUTIONS COULD HOLD A SIGNIFICANT ROLE IN THE EVOLUTION OF THE UTILISATION OF GNSS BY FARMERS ACROSS THE VARIOUS APPLICATION DOMAINS

1.1 METHODOLOGY

The following figure details the methodology adopted for the analysis of the agriculture user requirements.

1.2 SCOPE

This document is part of the User Requirements documents issued by the European GNSS Agency for the Market Segments where Position Navigation and Time (PNT) play a key role. Its scope is to cover user requirements on PNT solutions from the strict user perspective and the market conditions, regulations, and standards that drive them. Therefore, the document includes an analysis of the market trends on this particular segment, then performs a detailed analysis including the prospective uses of GNSS in this market finalising with a specification of user requirements in a format that can be used for System Engineering activities.

Figure 1: High-level methodology for the analysis of Agriculture User Requirements

OVERALL METHODOLOGY

1 Desk Research

Identification and detailed description of all existing agriculture applications

- All agriculture applications covered in Market Report v.5
- Agriculture applications found in other sources

Identification of user communities and key actors in value chain

- Presentation of main market players and key user communities
- Identification and definition of GNSS performance criteria relevant to the various agriculture applications

Segmentation of Agriculture Applications

- Analysis of GNSS techniques applicable to agriculture
- Definition and classification of applications in categories

Definition of the functions and level of performance required for each application

- Agriculture user requirements analysis based on open Secondary research information
- GNSS limitations, market/techno trends and drivers
- Table matching the main applications with the performance criteria

User requirement analysis – *draft 1*

SECONDARY RESEARCH INFORMATION

GNSS magazines - Coordinates, GPS World, Inside GNSS; ESA website; Articles on Google Scholar; Thesis and dissertations on specific database; European regulation or standard; Google

2 Stakeholders Consultation

Validation interviews

- Interview guide
- Selection of the consulted stakeholders
- Primary research: Interviews and reporting

User requirement analysis – *final version*

User Consultation Platform

- User requirements submitted to the first UCP forum for review and finalisation
- Update, validation and expansion of the User requirement analysis at each UCP

2019 update

In more detail, the document is laid out as follows. It starts with a market overview for Agriculture **(section 4)**, focussing on market evolution and key trends, and presenting the main market players and user communities. It then continues with an analysis of GNSS limitations in the agriculture domain, policy and regulatory framework and provides summary of conclusions.

- Section 5.1 and 5.2 describe precision agriculture applications and agri-logistics applications.
- Sections 5.2 and 5.3 provide a detailed overview of the user requirements across the various applications. This follows closely the classification adopted in Market Report v5 whilst providing insights to additional sub-segments. The analysis has relied on extensive desk research and was validated through interviews with key agriculture stakeholders.
- Additional user requirement considerations is addressed in section 5.4.

The document is intended to serve as an input to more technical discussions on Systems Engineering and evolution of the European GNSS systems so that space infrastructures are effectively linked to user needs.

INCREASED AND MORE SUSTAINABLE AGRICULTURAL PRODUCTION STRONGLY RELIES ON GNSS-ENABLED SOLUTIONS

02 EXECUTIVE SUMMARY

2019 update

This report aims at enhancing the understanding of market evolution, strongpoints, limitations, key technological trends and main drivers related to the uptake of GNSS solutions across the different agricultural application domains. These elements are essential in order to frame the appropriate technology and service offering development vis-à-vis the requirements of the respective users.

To that end, the report starts (chapter 4) with an overview of the GNSS agriculture market trends. The projected growth of the world's population to 9.7 billion by 2050[1], coupled with a higher caloric intake of increasingly wealthy people[2] and the ensuing increase of food demand, renders the intensification of food production imperative. Both trends will be pertinent in developing countries, where the demand for agricultural products will outpace local production capacities, thus creating a gap that can be filled via trade. Additional strain on global food production is placed by the under-nourishment of a large part of the global population, the rising costs of inputs (especially fertiliser and pesticide costs) and by heightened consumer awareness with regard to the origin of food (i.e. the farm-to-table principle) in the West. The need for enhanced, efficient and sustainable agricultural productivity is further amplified by the post-harvest waste of food (up to 30% in developing countries[3]) and by environmental and climate-change related aspects. **In this context, the need for a comprehensive global food security strategy that ensures increased food production while reducing the environmental impact of agricultural activities is absolutely critical.**

A KEY COMPONENT IN THE GLOBAL STRATEGY ADDRESSING RISING FOOD DEMANDS LIES IN THE UTILISATION OF SCIENCE-BASED AND INFORMATION TECHNOLOGY-ENABLED SOLUTIONS

A key component in such a global strategy addressing rising food demands lies in the utilisation of science-based and, in particular, information technology-enabled solutions. In fact, over the past few decades, a number of solutions relying on technologies that have been developed for, or adapted to agricultural activities has emerged. With GNSS holding a predominant position, other technologies such as GIS, remote sensing through satellites or RPAS, optical sensors for nitrogen content and canopy condition, machine vision systems, gamma-radiometric soil sensors, etc. have been deployed across a wide range of applications. **The utilisation of the various different enabling technologies and the combination of the different types of data they generate, has given rise to Precision Agriculture (PA).**

Defined as a farming management concept that enables the observation, measurement and response to site-specific aspects and variabilities in crops and animal-rearing aspects, **PA has demonstrably contributed in increasing yield and productivity while controlling costs and reducing the environmental impact of agricultural activities.** Precision Agriculture techniques essentially consist in the precise and effective application of inputs including fertilisers, pesticides, water resources, labour and machine hours. Their adoption depends on a number of different parameters including geographical location, climate, crop type, field and farm size, diversity of production/farming chains, available technical developments and social aspects. Thus far, PA solutions have been more widely and successfully adopted in arable land farming, especially in large farms of the main grain-growing areas of the USA and Europe. Meanwhile, an increasing trend of adoption is observed in other crops (fruits, vegetables),

1 UN Department of Economic and Social Affairs: *World Population Prospects: The 2015 Revision*.
2 The global middle class will increase from 50 to 70% by 2050 according to the 2015 GAP Report of the Global Harvest Initiative
3 FAOSTAT accessed in June 2015

viticulture and Precision Livestock Farming (PLF)[4]. An overview of PA applications is provided in section 5.1.

Apart from PA, a number of information technology-driven solutions have been targeting **agri-logistic applications.** The use of real-time information applications allows the efficient tracking and tracing of the farm assets, either in order to ensure their optimised utilisation (e.g. farm machinery monitoring) or to enable the geo-traceability of farm products. Section 5.2 covers these elements.

Despite the varying successes and uptake rates of the various technology-driven solutions for agriculture, mainstreaming and extending their adoption requires **a number of technological, economic and awareness-related challenges to be addressed.** This includes solutions and business models tailored to the reality of small and medium farms, smart solutions for integrated information management farming systems, further R&D on the ways that new technologies such as drones and Internet of Things can be leveraged and, very importantly, appropriate mechanisms to reach out, include and consult farmers and cooperatives on all of those aspects. These aspects are presented in annex A1.4 whilst GNSS limitations are described in section 4.4. In addition, the policy and regulatory framework underpinning several developments related to the utilisation of technological solutions in agriculture are considered in section 4.6.

The critical role of farmers in providing their concrete user requirements, already at the level of the development of the technology as well as in relation to dissemination, has been recognised both in the framework of research projects but also at the institutional level. Recently the dedicated Focus Group on "Mainstreaming Precision Farming"[5] set up by the European Innovation Partnership on Agriculture, has placed on top of their recommendation list the need for *"Farmers and cooperatives to play a major role in innovation and in research on decision support systems and technical solutions to current problems".*[6]

Driven by this critical need, **this report presents a user requirement analysis across the different GNSS-enabled or supported applications used in agricultural activities** (chapter 5 and 6). The emphasis of this analysis is set on performance requirements and on the specific proposition of the relevant E-GNSS services (EGNOS OS, EDAS, Galileo OS, and Galileo HAS) in meeting them.

Finally, the report concludes with a series of tables **summarising the PNT system requirements for the various applications analysed herein.**

4 Depending on animal type - most commonly cows
5 https://ec.europa.eu/eip/agriculture/en/content/mainstreaming-precision-farming
6 EIP Focus Group, *Precision Farming Final Report*, November 2015

03 REFERENCE DOCUMENTS

Id.	Reference	Title	Date
[RD1]	GSA Market Report 5	GSA GNSS Market Report Issue 5	May 2017
[RD2]	GSA Market Development Strategy	GSA Market development strategy and implementation plan (Agriculture)	October 2014
[RD3]	EP study on Precision Agriculture	European Parliament – *Precision Agriculture: An opportunity for EU farmers - potential support with the CAP 2014-2020*	June 2014
[RD4]	EIP-AGRI Focus Group on Precision Farming	EIP-AGRI – *Focus Group on Precision Farming – Final Report*	November 2015
[RD5]	GAP Report 2015	Global Harvest Initiative – *Global Agricultural Productivity Report*	October 2015
[RD6]	UNIFARM User Requirements	UNIFARM – *DEL 6.2: UNIFARM User Requirements*	March 2013
[RD7]	KPMG Food Value Chain Report	KPMG – *The agricultural and food value chain: entering a new era of cooperation*	May 2013
[RD8]	The UNIFARM State of Play	UNIFARM – *GNSS Use in Agriculture*	June 2013
[RD9]	Roland Berger Precision Farming Report	Roland Berger – *Business opportunities in Precision Farming: Will big data feed the world in the future?*	July 2015
[RD10]	Graham Precision agriculture article	Lorelei Graham – *Precision agriculture on the global stage*	September 2014
[RD11]	Explanation of GPS/GNSS Drift	Alabama Cooperative Extension System – *Precision Agriculture Services - Explanation of GPS/GNSS Drift*	November 2010
[RD12]	Overview of GPS Guidance Systems	The Ohio State University Extension – *GPS Guidance Systems: An Overview of the Components and Options*	May 2002
[RD13]	GNSS-Based Auto-Guidance in Agriculture	V.I. Adamchuk, T.S. Stombaugh, and R.R. Price – *GNSS-Based Auto-Guidance in Agriculture*	August 2008
[RD14]	Introduction to Prescription Maps for Variable-Rate Application	Alabama Cooperative Extension System – *Introduction to Prescription Maps for Variable-Rate Application*	January 2009
[RD15]	Overview of Variable-Rate Technology	Alabama Cooperative Extension System – *Overview of Variable-Rate Technology*	January 2009
[RD16]	Precision Farming Tools: Variable-Rate Application	Virginia Cooperative Extension – *Precision Farming Tools: Variable-Rate Application*	Not specified
[RD17]	EGNOS for yield mapping	*EGNOS for yield mapping: the power of knowledge*	Not specified

Id.	Reference	Title	Date
[RD18]	Basics of Yield Monitor Installation and Operation	Cooperative Extension Service – *Elements of Precision Agriculture: Basics of Yield Monitor Installation and Operation*	June 1999
[RD19]	Yield Monitoring and Mapping	Alabama Cooperative Extension System – *Yield Monitoring and Mapping*	July 2010
[RD20]	GNSS Reflectometry	Egido et al. – *GNSS-R sensor sensitivity to soil moisture and vegetation biomass and comparison with SAR data performance*	October 2013
[RD21]	Remote sensing using GNSS	Jin, S., Feng, G.P. and Gleason, S. – *Remote sensing using GNSS signals: Current status and future directions*	February 2011
[RD22]	Remote Sensing for yield monitoring	Rembold, F., Atzberger, C., Savin, I., Rojas, O. – *Using Low-Resolution Satellite Imagery for Yield Prediction and Yield Anomaly Detection*	April 2013
[RD23]	Precision Soil Sampling For Alabama Farms	Winstead, A.T., Shaw, J.N., Mask, P.L., Norwood, S.H. – *Precision Soil Sampling For Alabama Farms*	January 2007
[RD24]	On-farm geo-traceability	Granndigirard et al – *On-farm geo-traceability as advanced tool for a competitive and sustainable agriculture*	May 2007
[RD25]	Overview of CAP Reform 2014-2020	European Commission – *Overview of CAP Reform 2014-2020*	December 2013
[RD26]	2013 Precision Agricultural Services Dealership Survey Results	Holland, J.K., Erickson, B., and Widmar, D.A. – *2013 Precision Agricultural Services Dealership Survey Results*	November 2013
[RD27]	Drivers of Precision Agriculture Technologies Adoption	Pierpaoli, E., Carli, G., Pignatti, Canavari, M. – *Drivers of Precision Agriculture Technologies Adoption: A Literature Review*	September 2013
[RD28]	PPP versus DGNSS	Rizos, C., Janssen, V., Roberts, C. and Grinter, T. – *PPP versus DGNSS*	October 2012
[RD29]	Remote sensing in agriculture	Atzberger, C. – *Advances in Remote Sensing of Agriculture: Context Description, Existing Operational Monitoring Systems and Major Information Needs*	February 2013
[RD30]	China's agricultural challenges	PWC – *China's agricultural challenges: Roads to be travelled*	October 2015
[RD31]	Precision in Crop Farming	Heege, H.J. – *Precision in Crop Farming: Site-Specific Concepts and Sensing Methods: Applications and Results*	July 2013
[RD32]	The Precision Agriculture Revolution	Lowenberg de Boer, J. – *The Precision Agriculture Revolution: Making the Modern Farmer*	June 2015
[RD33]	EU Satellites Precision Farming	Hutchison, P. – *Analysis: Could new EU satellite revolutionise precision farming in Europe?*	August 2015

Id.	Reference	Title	Date
[RD34]	RTK GNSS Receivers	Gakstatter, E. – *RTK GNSS Receivers: A Flooded Market?*	March 2013
[RD35]	A global perspective on precision agriculture	Loanard, E. – *A global perspective on precision agriculture*	November 2013
[RD36]	Controlled traffic farming	CTF Europe Ltd. – *Controlled traffic farming*	2013
[RD37]	Silicon Valley comes to agriculture	Willie Vogt, W. – *Silicon Valley comes to agriculture*	February 2015
[RD38]	Galileo CS GNSS High Accuracy and Authentication	InsideGNSS – *Galileo's Commercial Service: Testing GNSS High Accuracy and Authentication*	February 2015
[RD39]	Precise Point Positioning (PPP)	Murfin, T. – *Look, No Base-Station! Precise Point Positioning (PPP)*	March 2014
[RD40]	Agricultural monitoring	European Commission (JRC) – *Agricultural monitoring*	April 2014
[RD41]	User Requirements Interviews	VVA – *User Requirements Interviews*	March 2016
[RD42]	Viticulture state-of-the-art	Matese, A, Di Gennaro, SF – *Technology in Precision Viticulture: a state of the art review*	March 2015
[RD43]	Site-specific viticulture	Tisseyre et al., *New technologies and methodologies for site-specific viticulture*	April 2007
[RD44]	Satellite Clock estimation for PPP	Chen et al, *Efficient High-Rate Satellite Clock Estimation for PPP Ambiguity Resolution Using Carrier-Ranges*	Nov 2014
[RD45]	GNSS Technology Report	GNSS User Technology Report issue 1	October 2016
[RD46]	User Requirements Interview	UCP follow-up interview with industry	January 2018
[RD47]	UCP 2017	Agriculture Session at the UCP. MoM (Ref. doc. GSA GSA-MKD-AGR-MOM-236049-UCP2017-Professional-Agriculture-v1.0)	December 2017
		Stakeholder consultation	
[RD48]	GSA-MKD-AGR-MOM-246175	User Consultation Platform 2018 – Minutes of Meeting of the Agriculture Panel	03.12.2018
		Drivers for User Requirements	
[RD49]	New CAP Regulation for monitoring approach	COMMISSION IMPLEMENTING REGULATION (EU) 2018/746 of 18 May 2018 amending Implementing Regulation (EU) No 809/2014 as regards modification of single applications and payment claims and checks	22.05.2018
[RD50]	The CAP after 2020	Modernising and simplifying the Common Agricultural Policy	June 2018

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04 MARKET OVERVIEW AND TRENDS FOR AGRICULTURE

4.1 MARKET EVOLUTION AND KEY TRENDS

Precision Agriculture and Agri-logistic applications lie at the core of an era when technology-based innovations have been increasingly contributing in ensuring efficient use of resources, maximising output and profitability and supporting sustainable, eco-friendly farm practices. Driven by the need to meet growing global demand for food, increased attention to crop health and yield, pressure on cost-effectiveness and reduced environmental impact, and supported by government incentives and subsidies, farmers have been increasingly taking up precision agriculture solutions. According to recent studies by Roland Berger (July 2015) and Research & Markets (September 2015), the global precision agriculture market will grow with a CAGR of 12% through 2020, whilst the total market value will cross $5.5 Bn by then.

THE GLOBAL PRECISION AGRICULTURE MARKET WILL GROW WITH A CAGR OF 12% THROUGH 2020

This growth is also reflected in the uptake of GNSS-based solutions in agriculture. According to the latest EUSPA GNSS Market Report, the global annual shipments of GNSS devices are expected to increase more than threefold by 2025, while the penetration of GNSS is expected to reach more than 50% by then. Automatic steering holds the lead in generating revenues but is expected to witness the fastest price decrease due to high-accuracy applications becoming more readily available. Variable Rate Applications' revenue will be near to €900 Mn in 2025, as convincing business models are better established. This growth is mostly attributed to the rapid uptake of precision agriculture applications in developing countries (especially China, India and the Asia-Pacific region) and the uptake of sophisticated solutions in the most advanced areas (US, Europe and Australia).

A short overview of market evolution trends in these two geographical groups is provided below.

4.1.1 UPTAKE OF PRECISION AGRICULTURE IN DEVELOPING COUNTRIES

As the pressure for increased food production rises with a growing population (in India 55% of the population relies on farming[7]), intensified urbanisation and west-lifestyle trends (e.g. in China 30% more meat consumption per person[8]), developing countries - predominantly in Asia-Pacific - will be driving the growth of precision agriculture uptake. This is further supported by some of the most widespread precision agriculture solutions becoming more affordable (e.g. farm machinery guidance) and applicable to smaller land parcels, and by heavy government investments in agricultural R&D[9] and modernisation plans.

China has put forward a number of policy measures to tackle increased demand pressures, diminished farmland, polluted rivers and overuse of fertilisers, including liberalisation of leasing activities, the promotion of large-scale mechanised farms and the restructuring of agricultural subsidies. GNSS applications target mainly major crops such as wheat, sugarcane and cotton, but may soon be relevant to other high-value crops (fruits and vegetables) given the gradual shift of Chinese government's priorities.

India, on the other hand, suffers from low yield rates[10] despite being one of the world's biggest producers of agricultural products. Additional challenges arise from the ongoing trend for decreased farmland area and very small average farm sizes (80% having an area smaller than 2 ha).

7 http://www.huffingtonpost.in/dr-anil-k-rajvanshi/precision-agriculture-can_b_6845378.html
8 PWC, *China's agricultural challenges*, October 2015
9 According to a recent KPMG study China spends almost as much as the US in agricultural R&D
10 http://www.livemint.com/Opinion/nw9JKiPrDPpqCuWfmoibPN/Indias-agricultural-yield-suffers-from-low-productivity.html

Other areas such as Brazil and Argentina in Latin America also hold strong promise for the uptake of GNSS-based precision agriculture solutions[11]. Whilst several large and highly-mechanised agricultural holdings already use sophisticated PA solutions, the largest part of planted areas does not. Ongoing efforts by Embrapa, the Brazilian Agricultural Research Corporation, coupled with key challenges (e.g. Brazil is the fastest growing country in terms of fertiliser application), have given rise to a number of applications (incl. machinery guidance, grid sampling and VRA) in different regions of Brazil. Similarly, in Argentina precision farming solutions are increasingly being picked up, supported by the Network for Precision Agriculture operating under the Instituto de Tecnología Agropecuaria.

4.1.2 UPTAKE OF SOPHISTICATED SOLUTIONS IN ADVANCED MARKETS

North America is currently the most technologically advanced region and the heartland of precision agriculture, with the highest installed base, followed by Asia-Pacifc. The shipments in North America will increase more than two fold between 2015 and 2025, proving that precision agriculture is progressively prominent amongst farmers from this region and that the industry is committed to technological innovations (accounting over 50% of all GNSS devices in 2016)[12]. Having on average large-sized and highly-mechanised farms, and also having to face high costs of labour relative to capital, US farmers have been savvy adopters of precision agriculture applications. A recent survey[13] conducted amongst dealership organisations in the US has shown that precision services such as soil sampling with GPS and guidance systems are the most popular amongst respondents. WAAS has a significant penetration (approx. 70%), whilst RTK solutions offered by public, commercial or public/commercial partnerships, are preferred for more advanced applications. The evolution of the market is driven by the gradual introduction of more advanced and more interconnected technological solutions (e.g. drones, IoT, robotics) and by the rise of big data analytics. This is exemplified by investors, including disruptive big data players such as Google investing a total of $2.4 Bn in agricultural technology start-ups in 2014[14].

AUTOMATIC STEERING HOLDS THE LEAD IN GENERATING REVENUES BUT IS EXPECTED TO WITNESS THE FASTEST PRICE DECREASE

In Europe, Western and Eastern countries move at a different pace and maturity level with regard to GNSS-based solutions' adoption. Western Europe boasts a highly-developed precision agriculture sector, with increased output and mechanisation, which is mainly driven by increased cost efficiency needs:

- According to the machinery industry in Europe (CEMA), 70-80% of new farm equipment sold now in Europe has some form of Precision Agriculture component.
- In the Netherlands, for instance, GNSS was penetrating well with 65% of the arable farmers using GNSS in their cultivation in 2016[15].
- The growth in the adoption of Precision Agriculture (PA) in countries such as the UK has shown that between 2009 and 2012 the proportion of farms using PA increased. The increase for GNSS was greatest, from 14% to 22%, for soil mapping from 14% to 20%, for variable rate application from 13% to 16% and for yield mapping from 7% to 11%[16].

Eastern Europe, on the other hand, starts at a lower level but grows at a greater pace, driven by the need for increased output. According to a study carried out by VVA in 2012[17], RTK, DGNSS and EGNOS will have market penetration rates of 25%, 8.5% and 67% respectively. Some of the main challenges that need to be overcome for the wider adoption of PA in Europe include investment risk, perceived complexity of PA solutions and availability of cost-benefit tools for the individual farms. The latter is particularly true for the uptake of PA in small-to-medium sized farms. Concerning market evolution trends, as also with other highly-developed in terms of PA countries (e.g. Japan, Australia, South Korea), the focus is placed on the adoption of novel technological solutions, including drones, optical sensors and future Information and Communications Technology (ICT, like 4G and 5G), whilst seeking integration of and with existing technologies into complete farm management systems.

11 According to the interviewee from AGCO Galileo value proposition is particularly interesting in South America - see [RD41]
12 GSA GNSS Market Report, Issue 5 (https://www.gsa.europa.eu/system/files/reports/gnss_mr_2017.pdf)
13 http://agribusiness.purdue.edu/files/resources/rs-11-2013-holland-erickson-widmar-d-croplife.pdf
14 http://www.rolandberger.be/media/pdf/Roland_Berger_Business_opportunities_in_precision_farming_20150803.pdf
15 https://www.euractiv.com/section/science-policymaking/news/europe-entering-the-era-of-precision-agriculture/
16 http://www.europarl.europa.eu/RegData/etudes/note/join/2014/529049/IPOL-AGRI_NT%282014%29529049_EN.pdf
17 http://www.vva.it/content/Upload/GNSSinAgriculture.pdf

4.2 MAIN MARKET PLAYERS

4.2.1 AGRICULTURE VALUE CHAIN

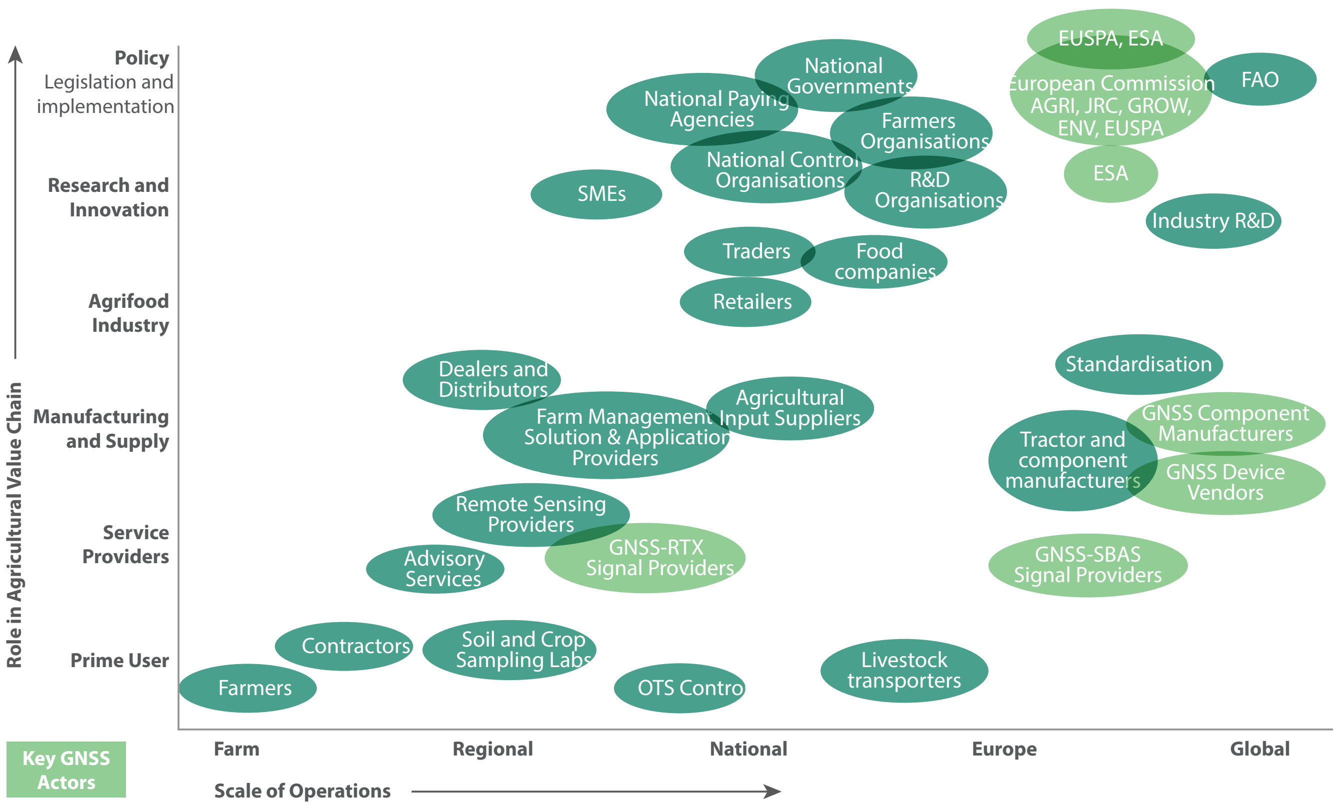
From the production of agricultural products at the farm level to the delivery of food, feed, fibre and bio-fuel to the end-consumers, the agricultural value chain is both complex and diverse. On one hand, it entails farmers, traders, food companies and retailers striving to meet global demand in terms of both quantity and quality. Key enablers for this objective are:

- Service providers assisting farmers in the uptake of sustainable and profitable farming practices through advice (e.g. FAS) or infrastructure (e.g. RTK networks and SBAS signals);
- Component and machinery manufacturers providing the means to carry out highly mechanised processes, as well as input companies (fertilisers, seeds, etc.);
- Specialised application developers and device vendors integrating different technologies in one solution, often for whole-farm management;
- R&D actors from farming groups to academia and industry; and finally,
- Legislation and policy bodies that put forward measures and regulation towards sustainable, competitive and environmentally-friendly agricultural activities.

These actors operate at different scales, ranging from individual farmers and high-tech agro-holdings at the farm level to dealers and distributors offering solutions at the regional level, and from nation-wide solution providers and national agencies (e.g. paying agencies) to multinational corporations. In this complex landscape (figure 2), GNSS-based solutions act as a key enabler for increased crop productivity, reduced costs (fuel, inputs, and labour) and lesser environmental impact. The relevant "GNSS in agriculture value chain" consists of augmentation/correction service providers (PPP, RTK, SBAS), GNSS component manufacturers, system integrators (within devices and machinery), and farm management solutions and application providers.

As far as GNSS requirements and technical specifications are concerned, three distinct groups in this landscape set the stage. Firstly, farmers and agricultural cooperatives that are looking for affordable, reliable and highly-performing technical solutions for the various phases of the crop and livestock growth cycle. Responding to such user requirements but also stimulating precision agriculture uptake through

Figure 2: Stakeholder landscape along the GNSS in agriculture value chain [RD9]



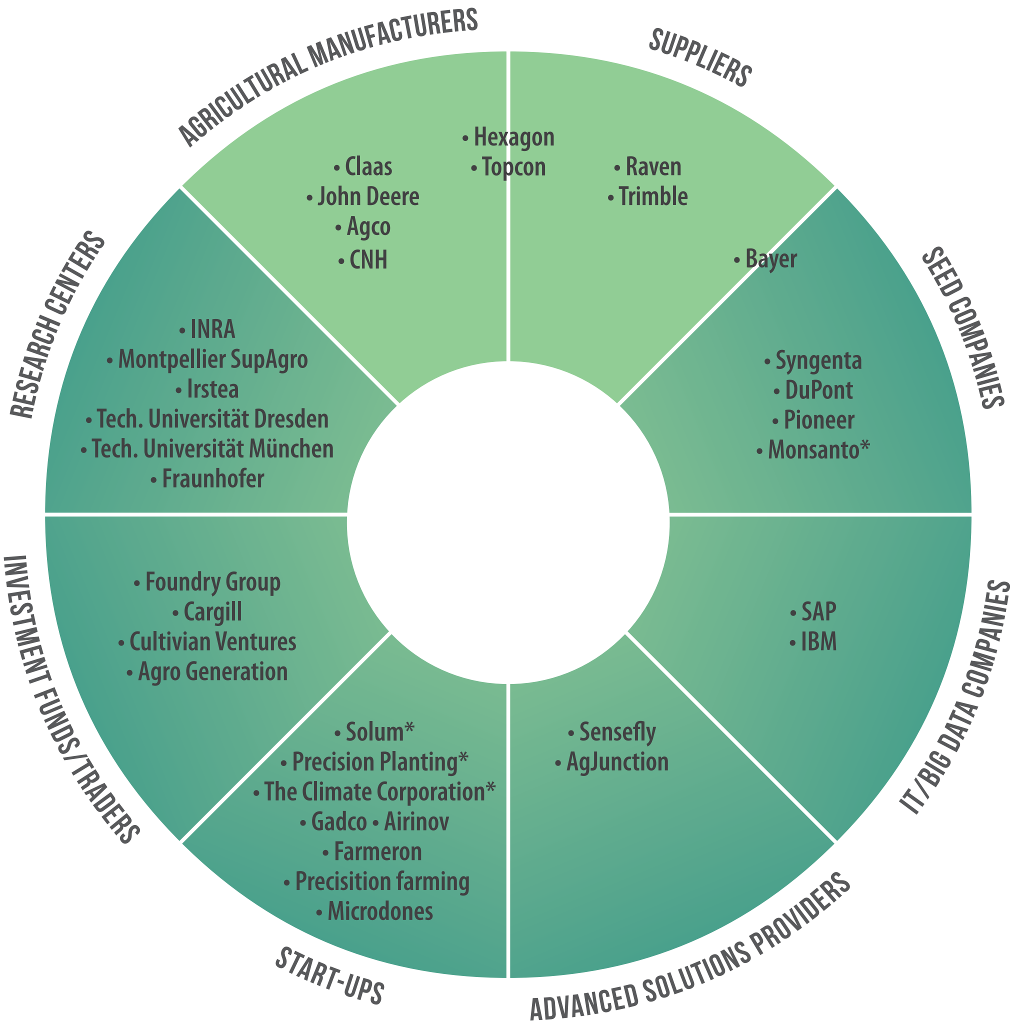
technology push are manufacturers, supply companies, device vendors and farm management solution, providers. Finally, setting the framework for the adoption of high tech solutions, and consequently constituting a key driver in the evolution of user requirements, lies in the responsibility of policy bodies at national, regional and international level. A brief insight into the technological trends that drive the evolution of the supply side is provided in the section below followed by an account of the different user communities.

4.2.2 SUPPLY-SIDE TRENDS

In recent years, precision agriculture has witnessed the introduction of novel or more advanced technologies, a paradigm shift towards integrated farm management solutions and the rise of disruptive business models[18] driven by the entry of new start-ups in the sector. The advent of the Big Data era often seen in the context of IoT, the RPAS-utilisation boom, improved optical sensors and advancements in automation and robotics, are shaping the technological landscape of precision agriculture both today and in the future. Globally leading OEMs and suppliers are forming alliances to provide distribution networks for the latest technologies and remain competitive. Thus, alliances such as those between CNH Global and Trimble, AGCO and Topcon, and AgLeader and Autofarm, as well as acquisitions such as those of The Climate Corporation by Monsanto and subsequently of the Precision Planting LLC by John Deere. In June 2018, Bayer successfully completed the acquisition of Monsanto and thus became the biggest agriculture supplier in the world. The evolution of the market place is outlined in figure 3.

These market evolution trends are linked to the evolving requirements of the different user communities which are described in the following section.

Figure 3: Evolution of the precision agriculture marketplace [RD9]



* Acquired by Bayer

18 http://farmindustrynews.com/precision-farming/silicon-valley-comes-agriculture

4.3 MAIN USER COMMUNITIES

4.3.1 FARMERS AND AGRICULTURAL COOPERATIVES

The number of farmers is estimated at 450 million globally, making farming the largest employment sector. Farm sizes vary from an average of less than 1 hectare in China to thousands of hectares in Russia or South America. Being the prime user of technological solutions aiming at enhanced cultivation and sustainable farming practices, farmers stand at the epicentre of user requirement definition and evolution. These depend on a number of factors, including most notably farm size, crop type and level of sophistication (directly related to access to finance). Given that most farmers are smallholders (global average under 2 ha), agricultural cooperatives have come to play a significant role in supporting and economically empowering small agricultural producers. Cooperatives provide a wide range of services including improved access to markets, finance, natural resources, information and technologies. In addition, they facilitate smallholders' participation in decision-making at all levels, enable the purchase of (shared) equipment and help towards striking better deals for inputs.

In Europe, COGECA the "General Confederation of Agricultural Cooperatives in the European Union", currently represents the interests of approx. 40,000 farmers cooperatives employing around 660,000 people and with a global annual turnover over three hundred billion euros throughout the enlarged Europe. Joined together with COPA (Committee of Professional Agricultural Organisations), they constitute the main representative body for farmers at European level. COPA-COGECA's[19] main role lies in lobbying the EU's public institutions to influence policy decisions affecting farmers and on facilitating exchanges that promote the uptake of solutions to common challenges. In that framework, they publish position papers and organise dedicated conferences such as the recent "Big Data for Cooperatives and Farmers"[20] that tried to shed light on aspects related to the uptake of precision farming solutions.

4.3.2 INDUSTRIAL ORGANISATIONS

A number of associations have been formed with the aim to promote joint R&D efforts in the agricultural sector. Amongst the most influential ones stand the:

- Agricultural Industry Electronics Foundation (AEF) which acts as a user platform that provides resources and know-how for the increased use of electronic and electrical systems in farming. AEF, representing directly or collaborating with 170 companies, has actively supported the standardisation of agricultural applications (notably ISOBUS) and carries out a number of joint projects.
- Agricultural Engineering and Technologies (AET) working group established under the European Technology Platform MANUFUTURE. The main role lies in formulating a strategic vision, identifying research fields, and defining a roadmap of R&D topics.
- CEMA, representing the European Agricultural Machinery Industry, provides a platform to address a number of challenges that farmers are facing (e.g. efficient farm management, harvest result maximisation, etc.) through the use of modern agricultural machinery.
- Agro EDI Europe and AgGateway, focussing on the evolution and standardisation of data exchange and e-connectivity respectively.

These organisations support dissemination and communication of various aspects of precision agriculture technologies and co-organise dedicated workshops (e.g. AET-UNIFARM, AET - ICT AGRI).

4.4 GNSS LIMITATIONS IN THE AGRICULTURE DOMAIN

GNSS is an integral enabling technology towards the implementation of site-specific farm management practices described previously. However, a number of limitations apply, which are typically overcome by employing the complementary technologies described in the previous section or by following best practices regarding the type of GNSS equipment used.

THE NUMBER OF FARMERS IS ESTIMATED AT 450 MILLION GLOBALLY, MAKING FARMING THE LARGEST EMPLOYMENT SECTOR

The most typical limitations are primarily linked to constraints related to the environment in which agricultural operations are carried out. Thus, in environments where there are natural (e.g. tree canopy) or artificial (e.g. buildings or highly-reflective surfaces) obstructions, and in areas with complex topographies, interference and multipath effects as well as limited GNSS signal availability, should be overcome by deploying complementary technologies.

For example, even though GNSS has been proven to work under vegetation cover, there may be a significant loss of signal depending on the type and moisture content of the vegetation. Furthermore, as far as RTK solutions are concerned, the positioning accuracy decreases as a

19 http://www.copa-cogeca.be/Menu.aspx
20 http://www.copa-cogeca.be/Download.ashx?ID=1386705&fmt=pdf

function of the distance of the rover receiver to the base station. Although this is typically overcome by deploying network RTK solutions, in geographical areas where this is not yet available (typically developing countries) the implementation of high-precision demanding applications (i.e. automatic steering) is hindered. In addition, poor GSM coverage – especially in developing markets characterised by large farms (e.g. Turkey, Kazakhstan, and Russia) – can impede the transmission of RTK corrections.

Another important limitation, related however to cost-benefit considerations rather than technical constraints, is that of applying PA solutions in small-to-medium sized farms. This point is further developed in the section below.

4.5 DRIVERS FOR USER REQUIREMENTS

As already presented in the previous chapters there is a great diversity of applications in agriculture for which GNSS is either the main enabler or a key component. These applications can be broadly categorised into four categories: Guidance systems, Variable Rate Applications, Site-Specific Data Analysis applications and tracking/delineation. Each of these application groups has its own GNSS performance requirements. From the user point of view, these requirements must be satisfied in order to accept the proposed technology.

THE TOP MOST IMPORTANT PARAMETER FOR THE ADOPTION OF GNSS-BASED PRECISION AGRICULTURE SOLUTIONS IS INCREASED PROFITABILITY

Most in-field cultivation operations require a centimetre to sub-metre accuracy level (pass-to-pass), provided by respectively through RTK, DGNSS or SBAS-based solutions. Certain in-field operations that require returning to exact locations at different times require in addition high-repeatability or otherwise very small GNSS drifts. On top of requirements strictly related to accuracy, users seek increased availability, reliability and, in the future, the authenticity of GNSS signals.

Apart from “quantitative” requirements, a number of “qualitative” requirements, mostly related to social or economic aspects are highly relevant for the adoption of the various solutions[21]. For example, farmer education, age, income and geographic location, all play a key role in the adoption of technological solutions. Other key aspects, also underlined in [RD41], include:

- Complexity - i.e. users seeking easy-to-use solutions;
- Interoperability/compatibility and standardisation - i.e. upgradeability of software to new versions and compatibility between different vendors solutions and between datasets;
- Ruggedness and resilience gave that farmers often operate in varying climatic conditions;
- Product/Solution reliability, or in other words delivery of what is promised;
- And, very importantly, convincing cost-benefit cases justifying the initial investment. To that end, the need for the development of reliable precision farming calculator tools that can take into account geographic regions and socioeconomic variability across Europe has been strongly reported in the recent EIP Precision Farming report[22]. This is particularly applicable to small-to-medium sized farms, for which tailored solutions need to be developed.

The **top most important parameter for the adoption of GNSS-based precision agriculture solutions is increased profitability**. Besides that, however, there exist several key parameters acting as drivers for the adoption of an elaboration of user requirements on GNSS-based precision agriculture solutions. This includes optimizing machine utilisation (automatic machine setting, automatic steering); obtaining greater quantities of reliable site-specific information (yield mapping, soil sampling); minimising overlapping/skipping costs and reducing labour and stress (guidance systems); optimising input utilisation (nitrogen sensors, geo-referenced soil sampling, VR maps); and enabling integrated farm management solutions (machine monitoring).

A more detailed analysis of the “quantitative” and some insights on the “qualitative” user requirements for the different application groups is provided in chapter 6.

4.6 POLICY AND REGULATORY FRAMEWORK

4.6.1 POLICY INSTRUMENTS ADDRESSING PRECISION AGRICULTURE

2019 update

In order to address **economic** (food security, globalisation, declining rate of productivity growth and price volatility), **environmental** (resource efficiency, soil and water quality, etc.) and **territorial** (depopulation and relocation of businesses out of rural areas) challenges, the EU Common Agricultural Policy (CAP) sets forth three high-level policy objectives

21 See for example Pierpaoli et al, *Drivers of Precision Agriculture Technologies Adoption: A Literature Review*, (2013)
22 https://ec.europa.eu/eip/agriculture/sites/agri-eip/files/eip-agri_focus_group_on_precision_farming_final_report_2015.pdf

2019 update

- Viable food production
- Sustainable management of natural resources and climate action
- Balanced territorial development

In meeting these objectives, precision agriculture - established as a successful farm management paradigm - can prove to be a key tool. PA solutions contribute not only to enhanced competitiveness of the agricultural sector (increased crop yield and profitability) but also to sustainable utilisation of resources and minimisation of environmental impact.

In that context, the specific policy measures and regulation put forward to ensure the fulfilment of long-term objectives, not only benefit from the uptake of innovative technologies such as GNSS but also act as a key driver for innovation.

4.6.2 CAP FOR 2014-2020 AND BEYOND

2019 update

The Common Agricultural Policy (CAP) establishes the legislative framework around a system of subsidies and other support programmes for agricultural activities in the European Union. Since 1962, and throughout a series of reforms, the CAP has not only supported farmers in their efforts to supply EU citizens with good quality and safe food; it has also been guiding the implementation of sustainable agriculture across the EU.

The CAP 2014-2020 reform maintains the two-pillar structure that was in place since 1999: **(1) direct payments and market measures**, and **(2) rural development.** Both pillars are aimed at meeting all three long-term CAP objectives more effectively, through an integration of the first pillar instruments with the regionally tailor-made and voluntary measures of the second pillar. The first pillar concerns direct payments to farmers that respect certain agricultural production and land use standards, whilst a new "green" direct payment that rewards farmers for respecting three mandatory agricultural practices (maintenance of permanent grassland, ecological focus areas and crop diversification), has been introduced. Financial support under the second pillar is implemented through national and/or regional rural development programmes (RDP).

Alongside these two pillars, a number of objectives that are relevant for precision agriculture have been introduced. This includes "improving agricultural competitiveness", "fostering innovation", "enhancing farm income", "providing environmental public goods" and "pursuing climate change mitigation and adaptation". On top of that, a number of articles of the CAP, describe measures that either benefit already today or could so in the future from GNSS-enabled or supported applications.

For instance, Article 17 concerns measures related to farm modernisation and intensification, as well as agri-environment-climate measures. In the first case, GNSS-based applications such as farm machinery guidance and automatic steering support increased crop yield, reduced carbon footprints and soil compaction (CTF). On the other hand, VRA can assist farmers in complying with the environment-related regulation. This applies, for example, to controlling and reducing the amount of nitrogen in the so-called Nitrate

Vulnerable Zones (NVZ)[23] through the use of variable N fertilisers; avoiding spreading on buffer strips (e.g. through Automatic Section Control); and saving water, labour and energy by using VRT sprayers for precision irrigation.

Article 28 puts forward measures to support farmers that undertake operations related to the agro-environment-climate commitments such as environmentally favourable extensification of farming; management of low-intensity pasture systems and integrated farm management and organic agriculture. In this scheme, farmers commit for a minimum period of five years, to apply environmentally-friendly farming practices, over and above legal obligations. GNSS-enabled precision agriculture solutions can support farmers in participating in this scheme.

Article 35 supports cooperation between at least two entities on joint pilot projects related to environmentally-friendly farming practices, e.g. efficient water management. Here too, precision agriculture can contribute to the corresponding requirements. Finally, Articles 14 and 15 foresee measures related to the uptake of innovative technologies in real farming practices. This includes training and knowledge transfer actions (Art. 14) to farmers to develop technical and environmental skills; and Farm Advisory Services (FAS) under article 15 for the delivery of best agronomic practices and uptake of innovative solutions. A prime example of such Farm Advisory Service is the "Be PRECISE"[24] cost-benefit calculator developed by the UK-HGCA to help growers weigh the costs and benefits of using precision farming technology on their farms. The need for robust advice that can be provided via FAS, and especially for cost-benefit backed advocacy on the uptake of precision farming techniques has been underlined as a top recommendation by the EIP-FG on Precision Agriculture[25].

PA SOLUTIONS CONTRIBUTE TO ENHANCED COMPETITIVENESS OF THE AGRICULTURAL SECTOR, SUSTAINABLE UTILISATION OF RESOURCES AND MINIMISATION OF ENVIRONMENTAL IMPACT

Finally, precision agriculture supported by GNSS-based applications can contribute in meeting the requirements put forward within the greening measures. Under this new element (that accounts for 30% of direct payments), farmers receiving an area-based payment are obliged to undertake various straightforward, non-contractual practices that benefit the environment and the climate. Thus, farmers with more than 10 ha of arable land have to comply with crop diversification requirements:

- Up to 30 ha: farmers have to grow at least 2 crops and the main crop cannot cover more than 75% of the land.
- Over 30 ha: farmers have to grow at least 3 crops, the main crop covering at most 75% of the land and the 2 main crops at most 95%.

In addition, farmers must maintain the ratio of permanent grassland to the total agricultural area, and must also ensure that at least 5% of arable areas (over 15 ha) is designated as an 'ecological focus area' dedicated to ecologically beneficial elements. Given that GNSS-enabled application can contribute to all three measures, greater uptake can be foreseen in the (near) future.

In this context, the new regulation introduced in May 2018 [RD49], attempts to modernise the implementation of checks for area-based payments and for cross-compliance requirements. This landmark change foresees that modern solutions such as geo-tagged photos (enabled by GNSS) and data from Copernicus Sentinel satellites are used to carry out checks. This new "monitoring approach" promises significant benefits for farmers and administrations alike [26]. The new rules will allow those member states that wish to do so to eventually replace or complement on-site checks with automated and less burdensome controls. Several member states have already indicated their intention to immediately start using new technologies such as geo-tagged photos.

2019 update

This modern approach is further reflected in the legislative proposals of the European Commission for the future of the common agricultural policy[27]. These are organised around 9 clear objectives and consider technology (including Galileo, EGNOS and Copernicus Sentinels) as a key enabler for CAP2020+ [28].

2019 update

4.6.3 OTHER APPLICABLE POLICY DIRECTIVES

Apart from the policy framework directly related to the CAP, a number of other directives and policy schemes are of relevance for the uptake of GNSS in agricultural activities. This is particularly relevant, in expectation of the authentication services of Galileo, ensuring better robustness against spoofing.

2019 update

23 This terminology was first introduced by the UK government https://www.gov.uk/guidance/nutrient-management-nitrate-vulnerable-zones
24 http://cereals-2.ahdb.org.uk/publications/documents/bePrecise.pdf
25 https://ec.europa.eu/eip/agriculture/sites/agri-eip/files/eip-agri_focus_group_on_precision_farming_final_report_2015.pdf
26 https://ec.europa.eu/info/news/modernising-cap-satellite-data-authorised-replace-farm-checks-2018-may-25_en
27 https://ec.europa.eu/info/food-farming-fisheries/key-policies/common-agricultural-policy/future-cap_en
28 https://ec.europa.eu/info/sites/info/files/food-farming-fisheries/key_policies/presentations/cap-technology-simplification_en.pdf

Thus, additional policy and regulation-driven GNSS applications are currently at work or can be anticipated in the near future. A brief overview is provided below:

- **Geo-traceability:** As described in the applications' section, the Regulation (EC) No 1/2005 foresees that road vehicles transporting livestock must be equipped with GNSS trackers. In addition, GNSS solutions make it possible to monitor environmental and location-based variables, communicate them to databases for analysis, and comply with food safety and traceability standards, as described for example in Directive 2001/18/EC on Genetically Modified Crops.
- **Environmental directives:** By enabling the exact measurement of field boundaries, regulating the use of inputs and geo-referencing site-specific crop data, GNSS can support farmers in complying with environmental directives such as Natura 2000, the Nitrates Directive and the Water Framework Directive. In addition, GNSS (in combination with Earth Observation) can support a number of environmental monitoring applications[29].

Finally, with the advent of fully autonomous farm machinery being expected in the near future, regulation may be expected to set the requirements for their operation (accuracy, availability, continuous connectivity, etc.).

4.6.4 POLICY AND REGULATORY STAKEHOLDERS

2019 update

Policies falling under the CAP or other directives are shaping the requirements for the use of GNSS-enabled solutions by farmers trying to comply with the specific measures. These policies are driven by strategic objectives set at EU level and are implemented through nationally or regionally established organisations of the Member States. Alongside European and national institutions, new structures such as the European Innovation Partnership "Agricultural Productivity and Sustainability" have been established with the aim to foster competitive and sustainable farming. A brief description of the various institutional actors follows.

2019 update

At **European Level**, the Directorate-General for Agriculture and Rural Development (DG AGRI) is responsible for the implementation of agriculture and rural development policy, the latter being managed in conjunction with the other DGs which deal with structural policies.

Specific Other DG's and associated agencies have specific responsibilities on subjects related to the implementation of precision agriculture. This includes:

- The **EIP-AGRI**, funded under the EU Rural Development Policy, and aiming at catalysing the innovation process in the agricultural sector by bringing research and practice closer together. To this end, the EIP-AGRI has set up a specific **Focus Group working on the topic of mainstreaming precision farming.** The purpose of the group is to: take stock of the state of the art of practice and research in the field of its activity; identify needs from practice and propose R&D and innovation directions, through operational groups or other project formats to test solutions and opportunities. The group, which consists of 20 experts from research, farming and industry has recently published a report on precision farming[30].
  - **DG GROW and EUSPA** managing the E-GNSS programmes and promoting the uptake of their applications in agriculture respectively
  - **DG CONNECT** has established the **"Smart farming and food security"** working group that explores how IoT scenarios/use cases could allow monitoring and control of the plant and animal products life cycle from farm to fork.
- The **JRC MARS** unit develops methods, tools and systems for use within agricultural monitoring activities applied to Europe, sub-Saharan Africa and other areas of the world. It provides scientific and technical support for the Integrated Administration and Control System's (IACS) implementation, cross-compliance implementation and information management linked to the CAP regulations. Crop yield forecasting is undertaken to provide monthly bulletins forecasting crop yields to support the CAP and issue early warnings in case of crop shortages.

At **National Level**, Member State National administrations, in particular, accredited paying agencies are responsible for the appropriate administration of direct payments to farmers applying for CAP aid and for the technical control of compliance with the specific measures. This includes the performance of the "on the spot" checks verifying the accuracy of field boundary measurements, for which as described earlier accuracy requirements differ between Member States (and thus the GNSS correction used). It also concerns the implementation at national level of the IACS and in particular the Land Parcel Identification System (LPIS) that covers all agricultural areas.

29 For a comprehensive overview see J. Awange, Environmental Monitoring using GNSS, Springer (2012)
30 https://ec.europa.eu/eip/agriculture/sites/agri-eip/files/eip-agri_focus_group_on_precision_farming_final_report_2015.pdf

Moreover, Rural Development managing authorities in the MS may decide on the relevance of PA techniques for their regional characteristics. Thus, in intensive crop production regions, they can put forward the utilisation of automatic steering systems that contribute to meeting the agri-environmental measures of the CAP.

TECHNOLOGY-DRIVEN AGRICULTURE IS RECOGNISED AS A FARM-MANAGEMENT APPROACH THAT CONTRIBUTES TO TACKLING GLOBAL FOOD AND ENVIRONMENTAL CHALLENGES

4.7 CONCLUSIONS

Technology-driven agriculture, encompassing in the case of GNSS, **precision agriculture and agri-logistic applications**, is widely recognised and increasingly practised as a farm-management approach that contributes to tackling global food and environmental challenges. With GNSS standing at the epicentre of site-specific management and data analysis, variable application of inputs and optimised farm machinery utilisation, farmers benefit from increased crop yield, reduced operational costs (fuel, labour, agricultural inputs), increased profitability and reduced environmental impact. This report has provided an overview of the state-of-the-art in different applications for which GNSS is a key enabler or decisive component, shed light on the current market, technology and R&D trends and outlined the key user requirements for GNSS.

The adoption of GNSS-enabled agriculture solutions is a function of the extent to which quantitative and qualitative requirements are met. In that context, improving E-GNSS positioning will require appropriate system evolution, identification and marketing of the unique proposition, as well as actions to stimulate wider acceptance by, and applicability to, farmers and their customised needs.

Precision agriculture is moving towards a paradigm which is increasingly integrated (different technologies and sensors) and "inclusive", i.e. targeting less mature countries/regions and less-advanced farms (size, mechanisation, awareness, etc.). This new paradigm is signalled by the introduction of new business models and technologies, such as remote sensing, RPAS, robots, IoT and future internet. The scope of analysing the evolution of user requirements vis-à-vis those developments is therefore much greater than what is currently presented.

2019 update

The validation of GNSS user requirements falling under both categories (quantitative/qualitative) has been pursued through targeted interviews [RD41] with representatives of key stakeholder groups. It has been further enhanced through the Agriculture Panels of the User Consultation Platform [RD47], [RD48]. In the future, additional emphasis should be placed on users' expectations vis-à-vis the EGNSS proposition, especially in relation to the new opportunities opening by Galileo HAS, dual frequency receivers (or even multi-frequency in the wake of PPP). This, coupled with related market development activities, would allow the realisation of the potential of E-GNSS in the technology-driven, evidence-based era that agriculture has entered.

05 USER REQUIREMENTS ANALYSIS

5.1 PRECISION AGRICULTURE APPLICATIONS

5.1.1 OVERVIEW

Precision Agriculture consists in the application of the *"right treatment in the right place at the right time"* [31]. Relying on the utilisation of various technologies - predominantly on precise positioning through GNSS, it enables fine-scale, site-specific management of agricultural production. The adoption of precision agriculture amongst farmers, steadily rising over the past few decades with the advent of low-cost, high-accuracy GNSS solutions, has been primarily driven by the need for improved crop yield and for the reduction of costs through the optimisation of inputs. Thus, by being able to precisely guide their farming equipment and accurately apply different inputs taking into account the variabilities of their fields, farmers have been able to minimise soil compaction, reduce the use of fuel, pesticide and fertilisers, and increase productivity. Other significant benefits include the reduction of environmental impacts and increased worker safety.

The most widespread and well-adopted PA solutions are related to the accurate and precise steering of tractors and other farming equipment. Methods such as machinery guidance, automatic steering and controlled traffic farming (CTF) enable machinery to move along repeatable tracks on the field, minimising pass-to-pass errors and overlaps, permitting better timeliness and allowing extended work periods (e.g. during the night, lower visibility, etc.). Equally important are Variable Rate Technology applications that allow the efficient

Figure 4: Overview of GNSS-supported precision agriculture activities along the crop cycle (adapted from CEMA[30])

31 Gebbers and Adamchuk, Precision Agriculture, 2010
32 http://www.cema-agri.org/page/precision-farming-0

utilisation of nutrients and chemical products in different areas of the field, as well as precise seeding and planting. In all cases, the key drivers for adoption by farmers include increased profitability and ease-of-use.

In the future, new applications are coming to the reality such as field levelling and drainage, implement guidance, grassland-related operations (where EGNOS could have an advantage), and machine telematics.

5.1.2 FARM MACHINERY GUIDANCE

Farm Machinery Guidance systems have significantly enhanced farm field operations such as spraying, fertilising, planting and harvesting. They utilise corrected GNSS signals for the precise determination of the deviations of the tractor from a reference line, thus aiding farmers in driving on the desired path. By reducing overlaps and skips between adjacent passes on the field, guidance systems enable increased driving accuracy, improve in-field efficiency, and allow working at night or under low-visibility conditions.

GNSS-based guidance relies either on a prior pass or on a fixed line. For **prior pass guidance**, the driver starts by manually steering the machinery on a first path along the field. Once the prior pass has been recorded, all subsequent passes across the field are carried out at a given distance from the prior pass. This distance is typically the swath width of the equipment. The prior pass method allows a good adaptation to the shape of the field. On the other hand, in **fixed-line guidance**, the first path is carried out along the so-called AB line connecting two predefined points. As with the prior pass guidance, all subsequent passes are defined by a given offset distance - typically the swath width - multiplied by an integer. Contrary to the prior pass guidance, each subsequent pass is not depending on its prior but is rather defined by the AB line, the offset distance and the respective integer.

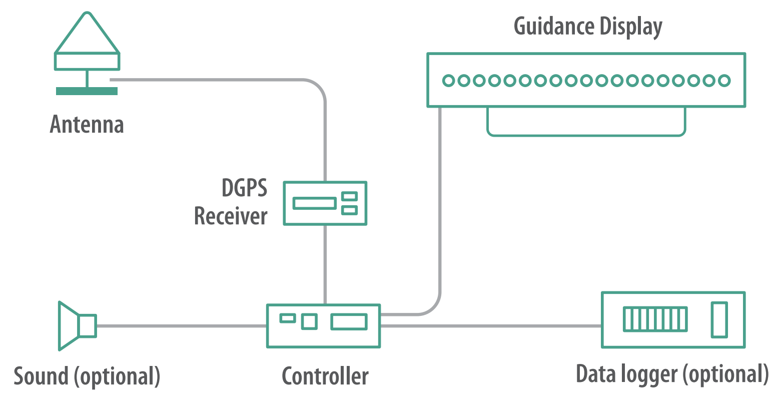
The two main GNSS-based guidance techniques are the **lightbar (or manual) guidance system** and the **automatic steering system**. Lightbar, being the simplest and least expensive solution, requires an operator to manually drive the vehicle. Lightbar systems include a GNSS (typically DGNSS or SBAS-enabled) receiver and antenna, a computer/microprocessor for the computation of cross-track errors relative to a guidance line, an interface that allows user inputs and LED light bars. The latter, embedded in a plastic case that is mounted in front of the operator, allows the displaying of cross-track errors. As long as the lights in the centre are lit up the vehicle is on track, but if the lights on either side are illuminated then the driver needs to correct the steering accordingly.

Lightbar guidance enables various field patterns including contour strips, irregular shapes and circular patterns for centre-pivot irrigated fields[33]. Modern lightbar systems include last-pass guidance, 3D graphics, day/night operation modes and as-applied mapping features; the latter enables to record if, where and when the machine was applying.

Lightbars are most commonly used for spreading, spraying and fertiliser applications. The typical pass-to-pass accuracy requirement ranges from 10 to 30 cm and can be enabled by SBAS and DGNSS. More accuracy-demanding farming processes such as steering of implements (planters, ridges, weeders, harvesters, etc.) are enabled by using high-accuracy RTK solutions.

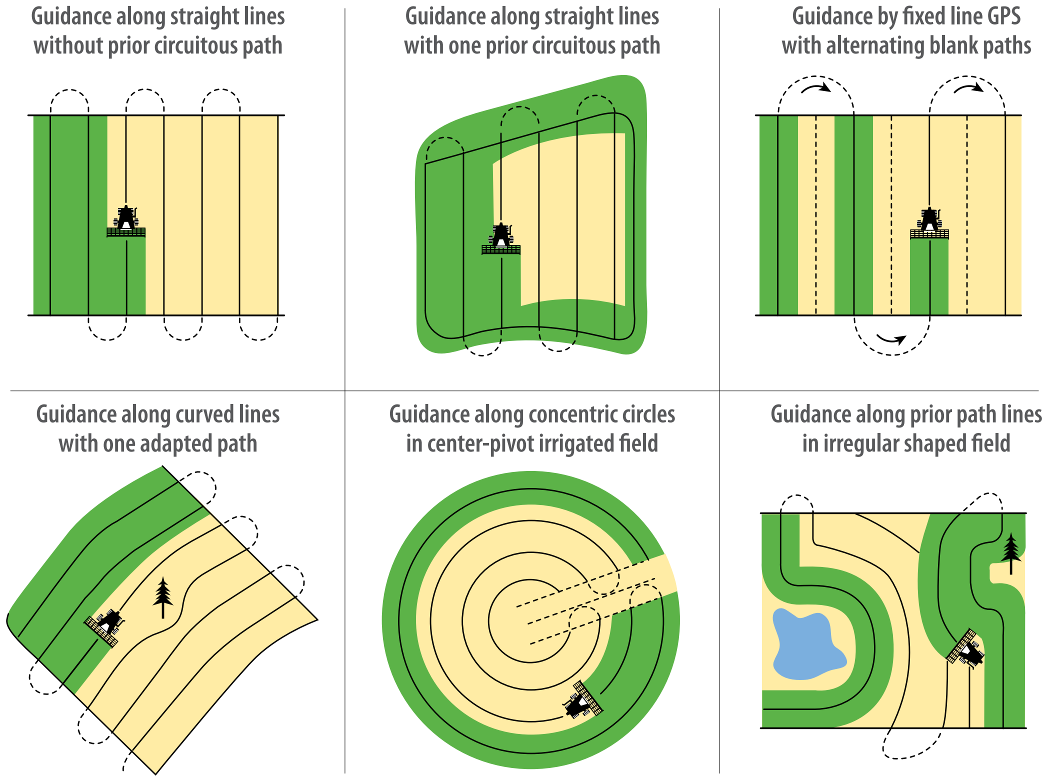
Being typically the first GNSS-enabled solution that farmers adopt, lightbar guidance systems are rather affordable (starting at approx. €1500), whilst commercial products are provided by numerous manufacturers[34].

Figure 5: Overview of the components of a guidance system [RD12]



33 Tim Stombaugh, Lightbar Guidance Aids, University of Kentucky, 2002
34 A comparative overview is provided here http://www.fwi.co.uk/machinery/gps-manual-tracking-simple-units-trested.htm

Figure 6: Examples of various In-field driving patterns [RD31]



5.1.3 AUTOMATIC STEERING

Automatic steering is a more advanced version of guidance that follows the same principles as lightbar guidance but instead of prompting the driver to make slight corrective manoeuvres, enables the vehicle to steer itself. This is accomplished either through an integrated electro-hydraulic control system or via an installed mechanical device inside the cab. The driver may still be present in order to perform the steering during turns while the auto-guidance system (enabled with the push of a button) steers the vehicle during the passes across the field. This allows the operator to concentrate on the supervision and operation of the implements.

Automatic steering systems consist of a GNSS receiver and antenna, controller, user interface module, attitude and steering feedback sensors and a steering actuator. Their price ranges from € 10,000 to € 40,000. The most expensive systems utilise RTK correction and typically provide better compensation for unusual vehicle attitude caused by rolling terrain, and more advanced control algorithms. Automatic steering systems using RTK can provide year-to-year repeatable accuracy to the level of 2.5 cm. RTK-based auto-steer guidance is used for applications such as planting, harvesting, installing drip irrigation and controlled traffic patterns. The latter refers to a whole farm approach also known as Controlled Traffic Farming (CTF), which has been developed with the aim to address soil compaction and erosion caused by intense machinery traffic on a field. The repeated, yet disorganised passes increasingly heavier machinery on a field have been causing negative changes (sometimes to a dramatic extent) to the quality of the soil[35]. To address this, CTF enables the confinement of all vehicles to the least possible area of permanent traffic lines. CTF essentially creates two distinct zones: the non-trafficked crop beds and the cropped or non-cropped traffic lanes, both of which are optimised for their different functions. It is currently considered as one of the most successful PA techniques, demonstrably reducing machinery and input costs and improving crop yields.

5.1.4 VARIABLE RATE APPLICATION

Variable Rate Application (VRA) solutions enable farmers to perform site-specific management of field variability and apply the appropriate amounts of inputs at a precise time and/or location. This is achieved through the utilisation of a variable-rate control system that is linked to the application equipment. Following the accurate mapping and measurement of characteristics such as acidity levels, and phosphorous, nitrogen or potassium content, farmers

35 See for example Gasso et al, Controlled traffic farming: A review of the environmental impacts, European Journal of Agronomy, 2013

use VRA to match the quantities of fertilisers to the need. The two types of VRA are **map-based** and **sensor-based**.

Map-based VRA adjusts the application rate according to a previously generated prescription map that informs the controller how much product to apply based on the exact location of the applicator on the field. The prescription map is developed based on soil testing analyses and other information such as yield maps, soil texture and terrain features. It may be supplemented with remotely sensed imagery, obtained either through satellites (e.g. through Copernicus Land Service[36]) or (un-)manned aerial vehicles. All this information is then combined into maps using GIS agricultural packages. By "reading" this prescription map and using a GNSS receiver determining the exact position of the machinery in the field, VRA enables the controller to apply inputs according to site-specific needs.

Sensor-based VRA requires neither previously compiled maps nor a positioning system. Instead, sensors on the applicator continuously measure crop characteristics and/or soil properties "on-the-go" (see figure 8 below). Using this information, a control system computes the required input for the soil or plants and orders the controller to appropriately deliver the input to the location identified by the sensor. Even if it is not a core component of sensor-based VRA, GNSS receivers enable the storage of geo-localised information for later use in farm management systems.

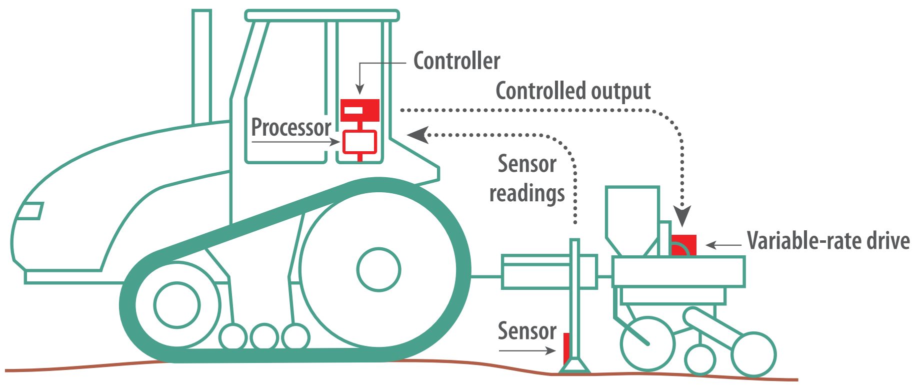
VRA solutions are currently on the rise and expected to be a key driver for PA adoption in the future[37]. At present VRA is most commonly used for the precise application of fertiliser (nitrogen, phosphorus and potassium), pesticides and lime; seeding; manure; tillage (taking into account soil compaction); and irrigation. According to an interviewee from AeroVision BV *"the best example of current [VRA] applications is the use of infrared sensors on top of the tractor…to adjust fertiliser application".* [RD41]

The accuracy requirements depend on the exact farming activity carried out; spreading, seeding and harvesting of bulk crops typically requires sub-metre accuracy provided by SBAS, whereas planting or weeding demands accuracy at the level of 2.5 - 10 cm offered by RTK (and in the upper-end by commercial DGNSS, i.e. >10cm).

The benefits of VRA utilisation in the various farming processes are significant both for the farmer and for the environment:

Figure 7: Grid-based vs. zone-based prescription maps [RD15}

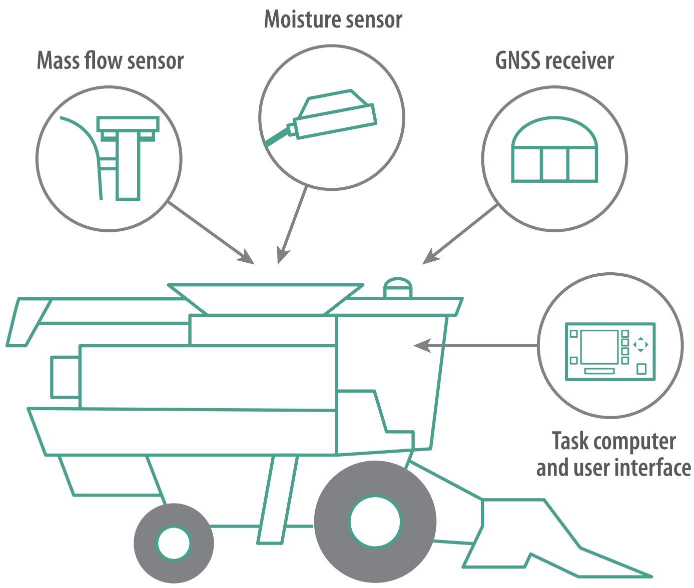
Figure 8: Sensor-based VRA [RD16]



36 Sentinel satellites will offer a resolution of 10 metres. Very-high resolution imagery (2.5 x 2.5 m pixels) has been thus far used only for the local component of Copernicus Land Service, i.e. for the Urban Atlas and selected zones (riparian or Natura 2000).

37 The latest GSA GNSS Market Report foresees that revenues for VRT will increase to about €900M in 2025.

Figure 9: Typical components of a grain yield monitoring system [RD18]



- **Economic Benefits**
    - Increased efficiency of input application
    - Reduced costs thanks to reduced quantity of consumables
    - Improved efficiency of equipment utilisation
    - Improved crop yields
- **Environmental Benefits**
    - Minimising over-application of inputs and consequently reducing the risk of pesticide/fertiliser runoff or leaching into water sources
    - Protection of environmentally sensitive areas

However, the complexity and the dependency of VRA applications on good connectivity between the tractor or the implement to external infrastructure is often an important adoption barrier. In addition, the level of return for using VRA varies widely by crop and technology, making the advancement of technology (e.g. with regard to yield mapping) and the elaboration of robust business strategies necessary (see [RD41]).

5.1.5 HARVEST/YIELD MONITORING

Harvest or yield monitoring systems enable the collection of accurate yield/crop data at a specific location and time. They are installed on a combine harvester and typically consist of a DGNSS receiver, a computer, a user interface and dedicated sensors that measure the amount and specific characteristics of crops harvested at the exact point where the harvester is located. Apart from accumulated grain weight, a readout of the harvested area and the corresponding yield rates, yield monitors may provide information such as soil moisture content and field elevation. The various yield data are stored and can be then plotted on maps via a GIS environment, allowing post-analyses and identification of crop performance trends. This is very beneficial for year-to-year farm management decisions on the application of inputs (see VRA above) in different areas of a field.

Harvest/yield monitoring equipment is used for various types of crops including wheat, corn, soybeans and cotton. Whilst the profitability of the utilisation of yield monitoring eventually depends on the way the yield data are used, a number of concrete benefits can be identified - especially when using GNSS-positioning:

- "On-the-go" comparison of yield rates and quality thanks to site-specific measurements
- Informed decisions on grain storage based on the measurement of grain moisture
- Inputs for site-specific application of inputs taking into account crop performance/status in various sites on a field

The positioning accuracy required for most yield monitoring processes is at the sub-meter level and can be well provided by SBAS (EGNOS). Of equal importance is the accuracy of the data measurements performed by the sensors. A number of errors related to material transport delays, moisture content, mass flow determinations and effective swath width must be taken into account and be counteracted through regular calibration.

5.1.6 BIOMASS MONITORING

Biomass monitoring involves the utilisation of remote sensing, airborne and near-ground sensors for the measurement of biomass/vegetation across an agricultural area. During the cycle from sowing to harvest, agricultural vegetation changes as a function of variables such as temperature, sunlight, and precipitation. Soil and plant characteristics, as well as the impact of the specific farming practices in use, can further affect the growth of vegetation. Changes in the health, density, vigour and productivity of crops affect the optical properties of the canopy. The use of remote sensing - especially in the red and infrared spectrum - and other proximal sensors enables the mapping of changes (essentially related to vegetation reflectance) across a field and with time, thus enabling the monitoring of crop development and growth. Low-resolution imagery is mostly relevant at regional scale, where agricultural agencies prepare inventories of what was grown in a certain area. In Europe, the MARS[38] Crop Yield Forecasting system operated by the JRC delivers among else vegetation state parameters that allow interpretation of biomass development of agricultural areas.

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On the other hand, high and very high-resolution imagery is used on a more local scale, but the revisit frequency is a constraint. The Copernicus Sentinel 1 (SAR in C-Band) and Sentinel 2 (multispectral) satellites hold significant promise for agricultural applications, offering a 10 m resolution (relevant for field scale mapping) and 5-day revisit time. The optical instruments[39] of the Copernicus Sentinel 3 satellites may also contribute to large-scale vegetation and crop condition mapping. As an alternative to satellite imagery airborne or RPAS-borne sensors are also being used, but they tend to be either more expensive (the former case) or more regulated (the latter case).

GNSS is used for on-site inspections of crop health and validations of the maps produced via other means. The accuracy required is, as with harvest monitoring, at the sub-meter level[40] and thus satisfied by SBAS. The knowledge of crop health and condition is then translated into farming strategies for the varying application of inputs (VRA) in different sites within a field. In addition to that, novel applications of GNSS-Reflectometry (GNSS-R) are being introduced for agriculture. This approach lies in the fact that the GNSS L-band reflected signal is sensitive to both the dielectric constant (moisture) and to structure (vegetation) allowing for an effective vegetation and biomass monitoring. The potential of this approach has been tested during two recent projects funded by ESA[41].

> THE ADOPTION OF PRECISION AGRICULTURE AMONGST FARMERS HAS BEEN PRIMARILY DRIVEN BY THE NEED FOR IMPROVED CROP YIELD AND FOR THE REDUCTION OF COSTS

5.1.7 SOIL SAMPLING

Soil sampling is one of the critical steps in crop management, given that the crop yield variability is strongly correlated to different soil characteristics in different sites within a field. Precision Soil Sampling enables the elaboration of farming practices that take this site-specific variability into account. In essence, by collecting accurate, site-specific information about soil characteristics such as fertility, soil-borne diseases and soil contamination, farmers can avoid over- or under-application of nutrients and other chemicals in different areas within their fields. In turn, this has a direct effect on increased yield productivity and reduced environmental impact.

Precision Soil Sampling utilises GNSS to geo-reference soil samples according to the site from where the sample was taken. These samples are then analysed in specialised laboratories, allowing for the measurement and characterisation of different soil parameters. GIS software tools are used to process, analyse and project the geo-referenced soil data in maps. There exist two primary methods for precision soil sampling: grid sampling and zone management.

In **Grid Soil sampling** the field is divided into square grid sections (typically 1-2.5 acres). GNSS is used to identify soil samples as taken from different grid sections. The laboratory analysis of the different samples results in site-specific nutrient needs that are then plotted using GIS and the geo-referenced database on nutrient application maps. These maps are then used for VRA (e.g. lime and/or fertiliser) on the grid pattern. Grid sampling provides a straightforward, less time-consuming and efficient way to better map variabilities in a field and identifies nutrient differences. However, given that the grid pattern is often arbitrarily defined, there is a danger that the grid may encompass areas that would be normally treated differently.

In **Zone management**, areas within a field with similar soil or yield properties are grouped together and managed

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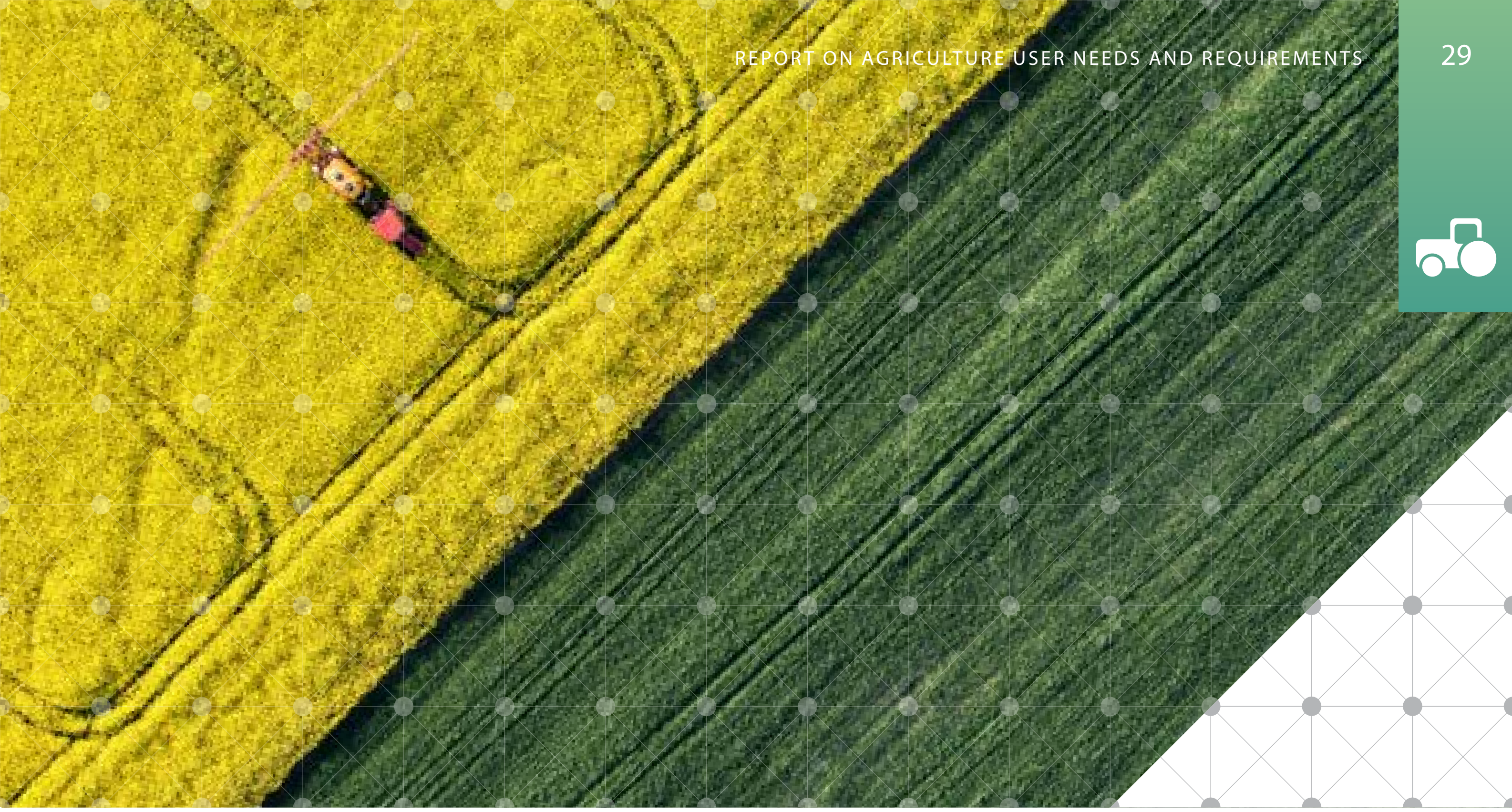
38 MARS: Monitoring Agricultural Resources https://ec.europa.eu/jrc/en/mars
39 Ocean and Land Colour Instrument (OLCI) - 300m resolution; Sea and Land Surface Temperature Radiometer (SLSTR) - 1km resolution http://www.copernicus.eu/sites/default/files/documents/Copernicus_Factsheets/Sentinel-3_fiche.pdf
40 According to UNIFARM requirements it is a the level of 1 metre
41 For a review see the paper by Paloscia et al (2013)



accordingly. Crop management zones are created via remote sensing (satellite, aerial), soil surveys, yield and soil electrical conductivity maps or using the farmer's knowledge. The zones are plotted on a map with the help of a GNSS-enabled hand-held device and a GIS tool. Despite being initially more time-consuming (to establish the zones) zone management is considered to be more effective for the characterisation and management of field variabilities than grid sampling. The main reason is that the zones are defined as a function of spatially distributed soil and yield properties.

The accuracy required for Precision Soil Sampling is at metre/ sub-metre level and can be satisfied by SBAS.

5.1.8 LIVESTOCK TRACKING AND VIRTUAL FENCING

Precision Livestock Farming (PLF) involves the utilisation of information technologies for the management of livestock production and the monitoring of animal behaviour. Two key applications within PLF are enabled with the use of GNSS. Livestock tracking involves the use of GNSS-receivers embedded on the collars of individual animals (most common cows), that are used to track their behaviour with regard to grazing habits, thus enabling optimised grassland and food resources utilisation. In combination with other sensors (mortality sensor, thermometer, 3-axis accelerometer), GNSS receivers are also used to detect cow fertility or illness. Furthermore, they enable the so-called virtual fencing, whereby animals reaching the boundary of a pre-defined area receive a sound or electrical stimulus that prevents them from exiting it. The accuracy requirement for livestock tracking and virtual fencing is at the metre level and can be provided by SBAS or even (multi)GNSS receivers. It must be noted however that livestock tracking has not yet been taken up by end-users due to primarily the high cost of collars (see also [RD41]). An exception to that is the use of GNSS-enabled collars for scientific monitoring of wildlife[42].

The geo-referenced data can be collected continuously and stored in dedicated databases, thus permitting post-processing and use towards the elaboration of farming strategies related to animal feeding, pasture area management and herd management.

5.1.9 PRECISION VITICULTURE

Precision viticulture (PV) concerns site-specific farm management practices that support the optimisation of the oenological potential of vineyards. While the development of PV solutions is relatively more recent – as compared to PA, their application show significant potential especially in regions with high-quality standards for wine production (e.g. France, Spain, California, Chile, South Africa, Australia and New Zealand). In practice, PV makes use of site-specific observations that provide information on the spatial variability of the vineyards and support the elaboration of recommendations for better field management (w.r.t. quality, production volumes and sustainable practices). Thus, techniques previously described on soil sampling (see 5.1.7), yield monitoring (5.1.5) and to some extent variable rate applications (see 5.1.4) are employed by wine grape growers to optimise their productivity.

42 See for example http://www.sirtrack.com/index.php/terrestrialmain/gps/collar

The utilisation of GNSS in PV is therefore related to the geolocation of sensors or machinery within the field [RD42]. With regards to positioning accuracy, most PV applications require sub-metre solutions supported by DGNSS or SBAS. For activities such as planting, a greater precision is required (cm-level) and thus RTK solutions are deployed. In the case of soil sampling, GNSS is used to geo-locate the sensors embedded in agricultural machinery that measure soil properties such as electrical conductivity, pH, ionic nitrogen and potassium content across the vineyard. Similarly, in crop monitoring, there are various systems equipped with GNSS, which provide high-resolution screening of the canopy, allowing for the determination of the vigour, height and texture of the vines. As far as yield monitoring is concerned, there exist solutions such as the HarvestMaster HM570 that enable the georeferenced volumetric grape measurement, while other handheld devices (e.g. Spectron – a portable spectrophotometer with integrated GNSS) allow the measurements of parameters such as sugar, acidity and water content of grapes.

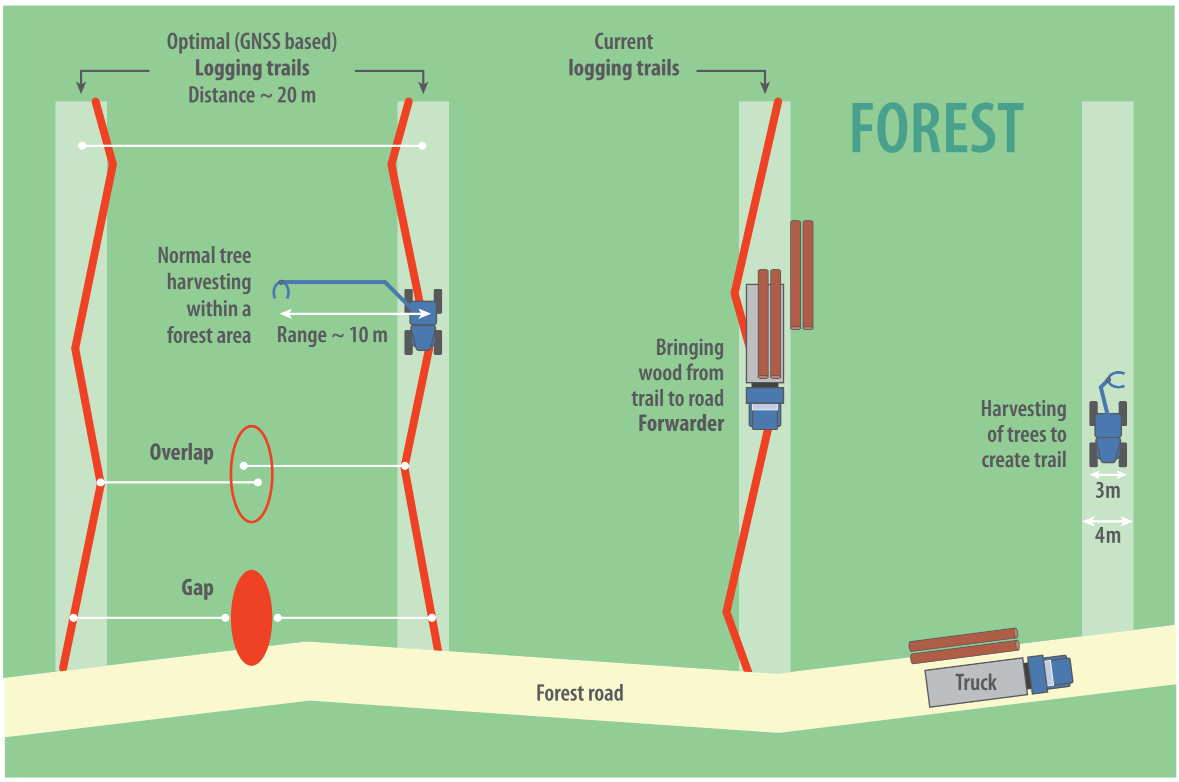
Another important trend in PV is that of product traceability (see also 5.2.2). This essentially involves the collection and storage of geo-referenced data that provide product information for the compliance with specific labels (e.g. organic wine, low environmental footprint contracts, etc.) and the conformance to regulations (e.g. EU regulation related to chemicals and herbicides) [RD43].

5.1.10 PRECISION FORESTRY

Precision forestry is defined[43] as *"planning and conducting site-specific forest management activities and operations to improve wood product quality and utilization, reduce waste, and increase profits, and maintain the quality of the environment"*. The utilisation of GNSS in precision forestry is often part of an integrated approach[44] where it is combined with other technologies (e.g. remote sensing, GIS, LIDAR, drones) for practices such as machine guidance (harvesters, hauliers, forwarders), surveying/mapping and logistics.

In the case of machine guidance in forest environments, the same overall description provided earlier (see 5.1.2) applies. As an example, harvesting of wood greatly benefits from mechanisation, whereby big harvesters are used to collect a large amount of wood in a short time period and with minimal environmental impact. To achieve this, it is important to avoid gaps and overlaps as the harvester creates logging

Figure 10: The process of GNSS-based wood harvesting[43]



43 Precision Forestry: Operational Tactics For Today And Tomorrow, Taylor S. et al. (2002)
44 See for example the Trimble Connected Forest solutions http://www.trimble.com/Forestry/index.aspx or Topcon smart forestry solutions https://www.topconpositioning.com/forestry

trails. To that end, precise GNSS positioning (sub-metre level) can be deployed (see figure below), allowing moreover the digital documentation of the process in support of an easier work by the forwarder that then piles the wood.

However, the forest environment (especially the dense tree canopy) introduces difficulties in precise positioning that are related to GNSS signal reflection, attenuation and short blockages. To overcome such difficulties several companies have developed products that can operate under harsh conditions. Nonetheless, R&D efforts such as H2020 Paradise46 are being undertaken with the aim to develop advanced GNSS signal processing techniques for adverse forest environments.

Besides machine guidance, GNSS is used for geo-referencing of objects in mapping activities such as forest inventory, whether performed on the ground or via aerial surveys (e.g. with LIDAR).

5.2 AGRI-LOGISTIC APPLICATIONS

Apart from the need for increased yield productivity and profitability, enabled through precise, evidence-based decision making with the help of GNSS and other technologies, farmers face a number of challenges related to the more economical, safe and environment-friendly management of their activities. Sparked by a series of food crises (e.g. BSE, dioxins and the recent HPAI in the US), consumer awareness, with regard to food safety and knowledge of its origin, has significantly risen. The farm-to-fork principle47 has introduced new food safety standards and related legislation, translating into a need for advanced geo-traceability of agricultural products. GNSS-enabled solutions, not only ensure the robust traceability of food but also open up new marketing tools (e.g. geographic origin or production method certificate) for farmers.

GNSS also supports the efficient and cost-effective management of agricultural assets. By enabling continuous tracking and monitoring of farm machinery, GNSS contributes to the elaboration of whole-farm strategies, logistical support and optimised use of resources. Whole-farm strategies are also supported by the accurate and precise knowledge of field boundaries, which is also critical in the context of CAP field measurements.

A detailed description of the main aspects of these three "agri-logistic" applications is provided below.

5.2.1 FARM MACHINERY MONITORING AND ASSET MANAGEMENT

Farm machinery monitoring and asset management are enabled through the utilisation of telematics solutions. Telematics systems make combined use of electronic communication networks and GNSS receivers that are typically embedded in modern farm machinery to monitor and report key information on the status of farming equipment. This includes information on machine location, hours of operation, maintenance status, data related to the specific PA process carried out and trouble codes. Modern applications enable the simultaneous tracking of multiple machines. The accuracy required for this application is at the metre or sub-meter level and can be satisfied by SBAS.

GNSS-ENABLED SOLUTIONS ENSURE THE ROBUST TRACEABILITY OF FOOD AND OPEN UP NEW MARKETING TOOLS FOR FARMERS

The data is collected in real-time and is stored via cellular or satellite systems onto web-based tools or mobile applications, enabling continuous monitoring but also evidence-based decision making in farm management. This data also assist in the optimisation of agricultural dealerships; continuous monitoring of the exact location, status and use patterns of leased equipment allows dealers to propose fit-for-purpose solutions for the particular farmer and also helps to detect errors and downtime. In addition, GNSS tracking of farm machinery ensures better security of expensive equipment against theft or misuse. All in all, farm machinery monitoring and asset management, is a modern, efficient approach to whole-farm management, whereby farmers enjoy greater operational efficiency and logistics support.

5.2.2 GEO-TRACEABILITY

The growing public awareness with regard to origin and production information of agricultural products, coupled with specific legislative measures to ensure the traceability of food "from farm to fork" has given rise to a growing market worth over $18 Bn by 2023[48], for which a number of GNSS-enabled applications (metre-level accuracy) are central. 2019 update

On one hand, EU legislation[49] foresees that transport of bovine, ovine, caprine and pigs in journeys longer than 8 hours is only allowed if the livestock movements and transport conditions are accurately recorded. Thus, livestock transport systems utilising GNSS trackers together with other

45 Source: "GNSS and today's forestry – a changing industry", presentation by Dr. Heinrichs at the Munich Summit 2016.
46 https://www.gsa.europa.eu/precise-and-robust-navigation-enabling-applications-disturbed-signal-environments
47 http://ec.europa.eu/dgs/health_food-safety/information_sources/docs/from_farm_to_fork_2004_en.pdf
48 https://www.alliedmarketresearch.com/food-traceability-tracking-market 2019 update
49 http://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:32005R0001&from=EN

sensors (measuring humidity, temperature, ventilation) have been deployed to monitor the animals' movements and their welfare conditions.

Food traceability concerns extend to cases where additional insurance against fraud is required; this is the case for the organic food sector, for Genetically Modified (GM) crops and for products from short supply chains (locally produced food that is labelled accordingly in supermarkets). In such cases, GNSS trackers are not only placed on animals but also on transport means (containers, trucks, ships) carrying food products. Novel traceability schemes allowing concrete knowledge of food origin and storage across the supply chain are being progressively implemented not only in relation to fresh[50] or frozen food but also wine. Other novel applications include restaurant trails with the aim to enable greater transparency (also in relation to tourism policies).

Certification schemes related to traceability have been put forward due to growing demand from food safety agencies but also the end-consumer. For instance, the Trade Control and Expert System (TRACES), consists of a network of veterinary authorities of member states and participating non-EU countries that use electronic sanitary certificates mandatory for tracking goods and live animals. Another example is the Agrivi traceability certificate which offers farmers and wine grape growers the opportunity to showcase information such how much fertiliser and nutrients have been used, other parameters related to the production effort and the field location from where the product originates. By using QR codes, it allows consumers to easily access this information.

Geo-traceability using GNSS has not yet been widely picked up. However, with stricter regulatory measures being put in place and with public demand for relevant information on the rise, it is expected to proliferate in the future.

5.2.3 FIELD DELINEATION

In the frame of the Common Agricultural Policy (CAP) budgetary support is provided to farmers that live up to strict standards relating to food safety, environmental protection and animal health and welfare. The size however of the support is directly related to the land parcels for which farmers request financial aid and the percentage/type of farmed areas within these parcels.

CAP monitoring and compliance lie under the auspices of paying agencies established at the national/regional level of the Member States. The measurements and verification of CAP compliance are carried out by professional EU inspectors that are required to use tools 'of a proven quality' for the measurement of agricultural parcels being claimed for subsidies. This requirement is applicable to Control with Remote Sensing (CwRS) and GNSS-based, On the Spot (OTS) checks by CAP inspectors. So far, most MS use ortho-imagery to create reference parcels that are registered within the so-called Land Parcel Identification System (LPIS). There is, however, an increasing utilisation of tablets with external GNSS receivers or handheld devices that are deployed for the measurement and on-spot checks of the precise parcel area (perimeter delineation, boundary changes, etc.). CAP certified receivers are also used by farmers when applying for CAP aid. The accuracy requirements, and subsequently the type of GNSS devices used (DGNSS real-time or post-processing, EGNOS-enabled), vary across the Member States. The regulation[51] does foresee however that "*A measurement tolerance shall be defined by a buffer of maximum 1.5 m applied to the perimeter of the agricultural parcel. The maximum tolerance with regard to each agricultural parcel shall not, in absolute terms, exceed 1.0 ha*". In this context, EGNOS CAP certified devices are widely used for the management and control of CAP compliance.

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In this context, the new regulation adopted on 22 May 2018 [RD49], foresees the increased use of technological solutions that will help to reduce the burden of physical inspections in the field. Thus, geo-tagged photos, EGNSS-enabled receivers (Galileo and EGNOS) and Copernicus Sentinel data are expressly mentioned as tools to be used for checking compliance with eligibility criteria, commitments or other obligations for the aid scheme and for cross-compliance checks. Looking specifically into geo-tagged photos, they are expected to be provided by the farmers or by inspectors in the context of monitoring, the updates of the Land Parcel Identification System (LPIS) or to substitute specific checks[52]. Physical inspections in the field should only be necessary if evidence collected with such methods is not conclusive. Whilst each Member State is free to implement this "monitoring approach" according to its needs and operational reality, the JRC and EUSPA are already working towards facilitating its uptake[53].

Apart from CAP-related measurements, accurate field delineation enables the creation and optimisation of cultivation plans. This is enabled through the combination of ortho-imagery techniques together with high-accuracy DGNSS receivers for the precise surveying of land parcel area, boundaries and morphology.

50 For example Trimble recently acquired HarvestMark to solidify its position in food traceability markets http://www.prnewswire.com/news-releases/trimble-acquires-harvestmark-to-provide-food-traceability-and-quality-control-300070050.html
51 http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:316:0065:0112:EN:PDF
52 https://marswiki.jrc.ec.europa.eu/wikicap/images/d/df/Sima.pdf
53 https://ec.europa.eu/jrc/sites/jrcsh/files/17-egnss_geo-taggedphoto_gsa.pdf

5.3 PERFORMANCE REQUIREMENTS BY APPLICATION

The Table 1 below provides a comprehensive view of performance requirements per application and immediate technological trends. It has been compiled using inputs mainly from the UNIFARM project, extensive desk research and industry interview ([RD6], [RD13], [RD19], [RD24], [RD25], [RD46], [RD47]). It is followed by an account of additional user requirement considerations across four combined application categories: guidance systems, variable rate applications, site-specific data analysis, and tracking and delineation. The specific PNT requirements relevant to those four combined application categories are also grouped in dedicated tables at the end of the chapter.

Table 1: Main GNSS User Requirements of Agriculture

Agriculture Application Categories	Application	Accuracy	Survey method and its relevance per app	Availability		Robustness	Authentication	Integrity and reliability	Size, weight, autonomy		Fixing and convergence time
		(Horizontal)		Canopy	Low Medium High	Low Medium High	Low Medium High	Low Medium High	Relevance	Autonomy	a few seconds a few min >20min
		mm-level cm-level sub-metre m-level	Relevance per App √ √ √ √ √ √	Yes/No					Yes/No	>1h >5h >8h >24h	
Precision Agriculture Applications	Farm Machinery Guidance	10 - 30 cm (pass-to-pass)	SBAS √ √ √ DGNSS √ √ RTK/N-RTK √ PPP/PPP-RTK √	No	High	Low	Low	High	N.A.	N.A.	a few min
	Automatic Steering	Down to 2.5 cm (pass-to-pass)	SBAS N/A DGNSS N/A RTK/N-RTK √ √ √ PPP/PPP-RTK √ √ √	No	High	Medium	Low	High	N.A	N.A.	a few min
	VRA-Low (spraying, spreading, harvesting bulk crops)	10 - 30 cm (pass-to-pass)	SBAS √ √ √ DGNSS √ √ RTK/N-RTK √ √ √ PPP/PPP-RTK √ √ √	No	High	Low	Low	High	N.A.	N.A.	a few min
	VRA-High (seeding, planting)	2.5 - 10 cm (pass-to-pass)	SBAS N/A DGNSS N/A RTK/N-RTK √ √ √ PPP/PPP-RTK √ √ √	No	High	Low	Low	High	N.A	N.A.	a few min
	Harvest/Yield Monitoring	sub-metre	SBAS √ √ √ DGNSS √ √ RTK/N-RTK √ √ √ PPP/PPP-RTK √ √ √	No	Medium	Low	Low	Medium	N.A.	N.A.	a few seconds
	Biomass Monitoring	sub-metre	SBAS √ √ √ DGNSS √ √ √ RTK/N-RTK √ √ PPP/PPP-RTK √ √	No	Medium	Low	Low	Medium	N.A	N.A.	a few seconds
	Soil Sampling	m-level/ sub-metre	GNSS standalone √ √ √ SBAS √ √ √ DGNSS √ √ √ RTK/N-RTK √ PPP/PPP-RTK √	No	Medium	Low	Low	Low	Yes	>8h	a few min

Agriculture Application Categories	Application	Accuracy	Survey method and its relevance per app	Availability		Robustness	Authentication	Integrity and reliability	Size, weight, autonomy		Fixing and convergence time
		(Horizontal)		Canopy					Relevance	Autonomy	
		mm-level cm-level sub-metre m-level	Relevance per App √ √ √ √ √ √	Yes/No	Low Medium High	Low Medium High	Low Medium High	Low Medium High	Yes/No	>1h >5h >8h >24h	a few seconds a few min >20min
Precision Agriculture Applications	Livestock tracking and virtual fencing	m-level	SBAS √ √ √ DGNSS √ √ √ RTK/N-RTK √ PPP/PPP-RTK √	Yes	High	Low	Low	Medi-um	Yes	>24h	a few seconds
Precision Agriculture Applications	Precision Viticulture (e.g. soil sampling and yield monitoring for vineyards)	sub-metre	SBAS √ √ √ DGNSS √ √ √ RTK/N-RTK √ √ PPP/PPP-RTK √ √	No	Medi-um	Low	Low	Medi-um	Yes	>8h	a few seconds
Precision Agriculture Applications	Precision Forestry	sub-metre	SBAS √ √ √ DGNSS √ √ √ RTK/N-RTK √ √ PPP/PPP-RTK √ √	Yes	High	Low	Low	Low	Yes	>8h	a few seconds
Agri-logistic Applications	Farm machinery monitoring and asset management	meter-level/ sub--metre	GNSS standalone √ √ √ SBAS √ √ √ DGNSS √ √ √ RTK/N-RTK √ PPP/PPP-RTK √	Yes	High	Medi-um	Medi-um	High	N.A	N.A.	a few seconds
Agri-logistic Applications	Geo-traceability	m-level	GNSS standalone √ √ √ SBAS √ √ √ DGNSS √ RTK/N-RTK √ PPP/PPP-RTK √	Yes	High	Low	High	Medi-um	N.A	N.A.	a few min
Agri-logistic Applications	Field delineation	sub-metre	SBAS √ √ √ DGNSS √ √ √ RTK/N-RTK √ √ PPP/PPP-RTK √ √	Yes	Medi-um	Low	High	Low	Yes	>5h	a few seconds

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Note 1: Quoted values for accuracy-related requirements should be considered as absolute within an average of 95% of the time.

Note 2: In the case of availability and authenticity the values shown are qualitative and have been based on the analysis carried out by Helios in the Market development strategy and implementation plan on agriculture.

Note 3: Precision viticulture (PV) involves the application of practices such as soil sampling and yield monitoring for vineyards. Thus, since these practices are covered individually no dedicated row for PV has been introduced. The same approach applies to the other tables in the chapters that follow.

Note 4: Precision Forestry has not been explicitly included as it refers mostly to machine guidance. However, it should be noted that the typically acceptable accuracy range in the forest environment is 0.5-1m.

The following Table 2 describes other key requirements and key trends in the agriculture domain.

Table 2: Other Key Requirements and Key Trends in Agriculture

Application	Other key requirements	Key trends
Farm Machinery Guidance	Interface and software aspects	Uptake in less-developed countries and by small/medium sized farms with limited experience in PA and reduced investment capacity; introduction of more advanced solutions; Uptake of PPP
Automatic Steering	High especially in CTF context -repeatability (RTK)	Uptake with increase of inputs costs; CTF; Full automation (including headlands); small robots
VRA-Low (spraying, spreading, harvesting bulk crops)	Less complexity; Automatic section control; cost-benefit tools; ISOBUS compliance	Availability of cost-benefit calculators; easier-to-use solutions; integrated farm management (yield mapping quality critical)
VRA-High (seeding, planting)	Less complexity; Automatic section control; cost-benefit tools; ISOBUS compliance	Availability of cost-benefit calculators; easier-to-use solutions; integrated farm management (yield mapping quality critical)
Harvest/Yield Monitoring	Sensor performance; Data quality/ compatibility	Optical and other sensors' advancements; Integrated Farm Management
Biomass Monitoring	Farm Management Integration; sensor performance	Optical and other sensors' advancements; Integrated Farm Management; GNSS-R
Soil Sampling	Sensor performance; automation	Sub-parcel coverage; Integrated Farm Management
Livestock tracking	Communication channels; collar functions	Decreased price; GNSS performance in attenuated environments; GNSS availability
Virtual Fencing	Communication channels; collar functions	Decreased price; GNSS performance in attenuated environments; GNSS availability
Geo-traceability	Regulation specs; tracker size; data recording	Stricter regulation leading to wider uptake; Authentication (OS-NMA)
Farm Machinery Monitoring	Compatibility with ability to monitor multiple devices; data handling	Integrated Farm Management; Multi-purpose devices (i.e. receivers already used in other functions)
Field Boundary Measurements	CAP compliance; documentation; multi-purpose	Galileo HAS (and OS-NMA)
Controlled Traffic, Strip tillage	Repeatability (also referred to as GNSS drift) is highly relevant for farming operations that require coming back to the exact same location at different times.	RTK approaches are the least affected by the GNSS drift
Multiple	Vulnerability to spoofing and jamming is becoming increasingly relevant especially when automated or fully-autonomous operations are concerned	Galileo Authentication offers increased robustness against spoofing

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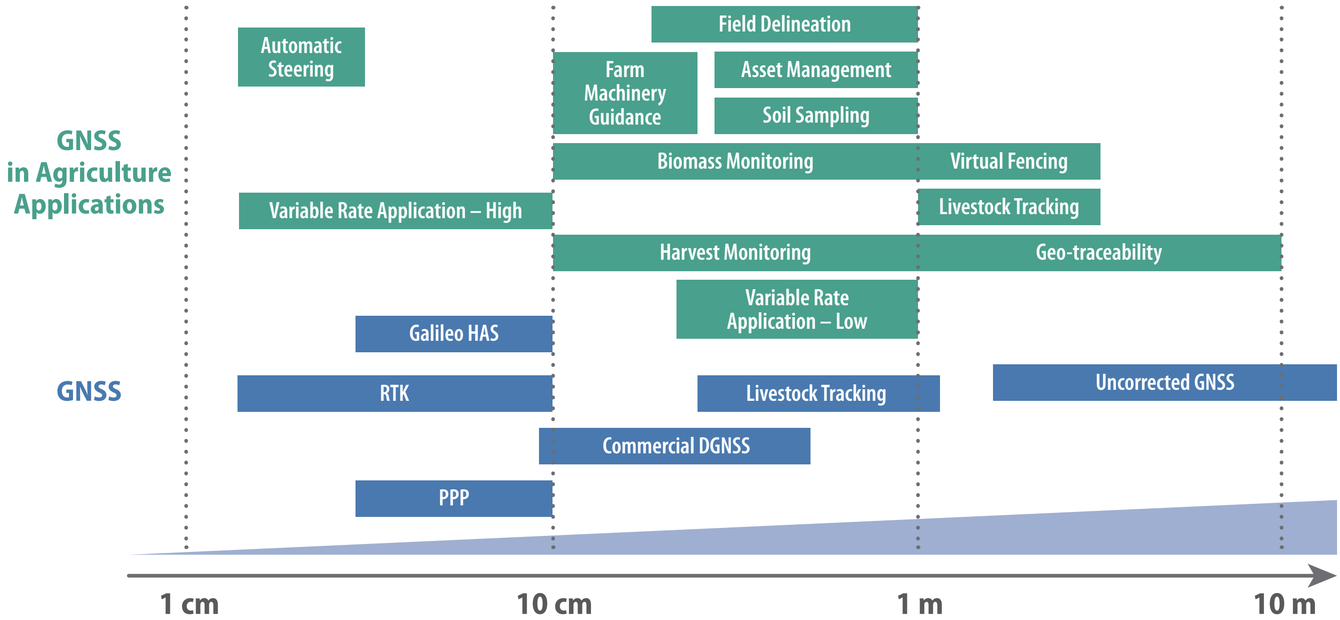
Below shown is a schematic that illustrates the positioning accuracy requirements per application.

Figure 11: Positioning accuracy requirements per GNSS application and technology



Adapted from UNIFARM

5.4 ADDITIONAL USER REQUIREMENT CONSIDERATIONS

5.4.1 GUIDANCE SYSTEMS

Whether referring to manual or automatic guidance, farmers' requirements are focused mainly on:

GNSS receiver performance: As indicated in the table above farm machinery guidance solutions should offer a pass-to-pass accuracy of 10 - 30 cm ensured through SBAS or DGNSS. Automatic steering solutions, as well as advanced machinery guidance (i.e. planters, weeders), require cm-level (2.5 - 10 cm) accuracy ensured via RTK solutions. For activities where the farmer returns to an exact location at a different time (e.g. strip tillage, Control Traffic Farming) high-repeatability is also necessary, translating into smaller effects from GNSS drift. RTK has essentially no impact from GNSS drift, whereas DGNSS and SBAS can have drifted in a range from 1.7 to 4.7 ft [54]. Apart from accuracy requirements, availability and continuity in the reception of GNSS signals (especially to mitigate operating environment and multi-path impacts) are critical.

In view of the automation/robotisation trends requirements on high-accuracy, availability and continuity will become increasingly stringent.

Software: The software should enable different patterns and manoeuvres to be performed, such as AB parallel guidance, A+ heading guidance, fixed contour and pivot guidance. In addition, the mapping functions should enable to store the worked area, record field boundaries and calculate the area in which the machine operated. Data compatibility and handling ease are also important.

Interface: Requirements on the interface include visualisation (2D/3D graphics, day/night mode, view of the field map, etc.) and hardware aspects (resistive touch, lightbar ease-of-use, etc.).

On top of these aspects, integrated mechanical or hydraulic/electric solutions are needed for automatic steering.

As far as "qualitative" aspects are concerned, ease-of-use and affordability remain on top of farmers requirements.

54 Mullenix et al, Explanation of GNSS Drift (2010)

5.4.2 VARIABLE RATE APPLICATIONS

The uptake of variable rate applications relies mostly on the elaboration of robust business strategies, justifying the costs needed as part of the investment in rather complex technologies, against the benefits from reduced input costs and improved yield production. For example, there is still no consistent business approach to the profitability of variable rate vs. uniform application of N-fertilisers. In addition, decision support tools need to implement truly-site specific solutions based on the prescription maps for varying inputs.

With regard to GNSS accuracy, requirements vary depending on the specific farming process in question. Thus, activities such as spreading, spraying and harvesting of bulk crops require sub-metre to decimetre accuracy provided by SBAS/DGNSS. On the other hand, demanding activities such as seeding, planting and weeding require cm-level accuracy provided by RTK. Furthermore, GNSS-based solutions should provide automatic section control capabilities (essentially turning the spreaders on and off depending on the exact site over which it moves). Other important aspects include ISOBUS compliance and VRA prescription map visualisation.

5.4.3 SITE-SPECIFIC DATA ANALYSIS APPLICATIONS

Falling under this group are applications that rely on different site-specific, geo-referenced data collection methods through the on-the-go ground (mainly optical) sensors, remote sensors, or physical sample sensors. Thus, yield/harvest monitoring, biomass monitoring and soil sampling described previously are considered here.

In all three cases, the positioning accuracy required falls in the sub-metre regime met by SBAS-based solutions. Of equal importance to positioning accuracy is the quality of the data collected either by optical (e.g. nitrogen and crop health sensors) and precision (mass flow, soil moisture, depth, magnetic, etc.) sensors on the ground, or of those onboard satellites or RPAS.

Process automation (e.g. in the case of soil sampling), data compatibility and handling, ease of documentation and integration within whole-farm management (e.g. yield maps or crop management zones are relevant for VRA) are also important to farmers.

5.4.4 TRACKING AND DELINEATION

This grouping contains on one hand monitoring and tracking applications (farm machinery monitoring, livestock tracking) and on the other delineation applications. GNSS accuracy requirements vary depending on the application from sub-metre to metre level; they can be typically satisfied by SBAS-enabled or DGNSS solutions.

Farm machinery monitoring requires the determination of the position of several farm assets with sub-metre to metre accuracy. A key aspect is a compatibility with existing devices mounted on the machines, thus avoiding the need for additional investment.

The user interface should provide a visualisation of the assets' position and paths projected on the field map. Advanced solutions providing farm-process specific data allow for the elaboration of whole-farm management strategies.

In the case of **livestock tracking** (of individual animals), GNSS accuracy requirements are less demanding (metre level) and can be satisfied by SBAS or even GNSS solutions. The functions of the collar within which the tracker is also embedded are of key importance. They should enable determination of the position using alternative tools in case of GNSS un-availability (e.g. GPRS, VHF), permit geo-referencing of data collected by other sensors (thermometer, mortality sensor, etc.) and deliver stimuli to constrain animals within specific boundaries (virtual fencing). With regard to adoption requirements, pricing still remains a key issue.

IN VIEW OF THE AUTOMATION/ ROBOTISATION TRENDS REQUIREMENTS ON HIGH-ACCURACY, AVAILABILITY AND CONTINUITY WILL BECOME INCREASINGLY STRINGENT

With regard to **field boundary delineation**, requirements are driven mostly by policy measures and regulation, both at EU (CAP) and at the national level. Thus, the different accuracy requirements imposed in the different Member States, necessitate the use of different correction services to meet them. The utilisation of GNSS receivers complying with these requirements for multiple purposes is an element sought by farmers. The same implication of policy and regulation concerns GNSS accuracy requirements on **geo-traceability**, whereby metre-level suffices. Greater awareness on environmental issues (in the case of field delineation) and of food security issues will drive user requirements in conjunction with policy measures reflecting this awareness. Galileo HAS (for delineation) and potential authentication (for both) applications may become relevant.

06 USER REQUIREMENTS SPECIFICATION

6.1 REQUIREMENTS FOR GUIDANCE SOLUTIONS AND VRA

Table 3: Requirements for Guidance Solutions and VRA

Id	Description	Type	Source
GSA-MKD-USR-REQ-AGR-0010	The PNT solution shall enable the determination of the position of the farm machinery with a pass-to-pass, horizontal accuracy of 10-30 cm (guidance and VRA-Low applications)	Performance (Accuracy)	[RD6]: UNIFARM User Requirements Mar 2013 [RD13]: GNSS-Based Auto-Guidance in Agriculture, Aug 2008
GSA-MKD-USR-REQ-AGR-0020	The PNT solution shall enable the determination of the position of the farm machinery with a pass-to-pass, horizontal accuracy of down to 2.5 cm (automatic steering and VRA-High applications)	Performance (Accuracy)	
GSA-MKD-USR-REQ-AGR-0030	The PNT solution shall enable the determination of the position of the farm machinery with an absolute horizontal accuracy of 60-80 cm	Performance (Accuracy)	
GSA-MKD-USR-REQ-AGR-0040	The availability of the location information provided by the PNT solution fulfilling its performance requirements shall be High.	Performance (Availability)	
GSA-MKD-USR-REQ-AGR-0050	The PNT solution shall provide satellite clock corrections with an update rate of the 30s or better (i.e. less than 30 seconds)[51]	Performance (Satellite Clock Corrections Update Rate)	[RD28]: Rizos et al. [RD44]: Chen et al.
GSA-MKD-USR-REQ-AGR-0060	The PNT information shall be transmitted in two or more bands (E1, E5, E6) thus enabling dual or triple frequency RTK and PPP solutions.	Function (Multiple Frequencies)	[RD38]: Galileo High Accuracy and Authentication Services

Note1: The year-to-year accuracy or GNSS drift is dependent on the GNSS differential correction technique used. The potential range of GNSS drift for SBAS-based solutions is ±1.5m. Different ways to take such errors into account are foreseen, but the most robust option is to use RTK solutions. On that basis, it was considered best not to include a separate requirement for the GNSS drift.

51 This requirement is essential for the utilisation of PPP in precise applications (cm-level)

6.2 REQUIREMENTS FOR SITE-SPECIFIC DATA ANALYSIS APPLICATIONS

Table 4: Requirements for site-specific data analysis applications

Id	Description	Type	Source
GSA-MKD-USR-REQ-AGR-0065	The PNT solution shall provide the position of the ground receiver with a horizontal accuracy within a range of 0.5-1m for Harvest, Yield and Biomass monitoring or soil sampling applications	Performance (Accuracy)	[RD6]: UNIFARM User Requirements Mar 2013 [RD19]: Yield Monitoring and Mapping, Jul 2010
GSA-MKD-USR-REQ-AGR-0070	The availability of the location information provided by the PNT solution fulfilling its performance requirements shall be Medium.	Performance (Availability)	

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6.3 REQUIREMENTS FOR TRACKING AND DELINEATION APPLICATIONS[56]

Table 5: Requirements for tracking and delineation applications

Id	Description	Type	Source
GSA-MKD-USR-REQ-AGR-0080	The PNT solution shall provide the position of the ground receiver with a horizontal accuracy within a range of 1-10 m	Performance (Accuracy)	[RD6]: UNIFARM User Requirements Mar 2013 [RD24], [RD25]
GSA-MKD-USR-REQ-AGR-0090	The availability of the location information provided by the PNT solution fulfilling its performance requirements shall be High.	Performance (Availability)	
GSA-MKD-USR-REQ-AGR-0100	The solution shall provide trust/confidence in the PNT information (for geo-traceability and field boundary measurement applications, e.g. geo-tagged photos)	Function (Authentication)	[RD38]: Galileo High Accuracy and Authentication Services

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56 This refers collectively to livestock tracking, virtual fencing, geo-traceability, farm machinery monitoring and field boundary measurements applications

07 ANNEXES

ANNEX 1: ANALYSIS OF PAST AND ON-GOING PROJECTS

This Annex presents an analysis of the most relevant EU-funded projects and initiatives which are either (1) focused on the technological development of specific GNSS solutions in the context of precision agriculture, or (2) which pave the way for the broader adoption of such solutions.

Research on precision agriculture has benefitted from increased attention over the last few years. Indicatively, the Horizon 2020 budget for 2014 to 2020 on Societal Challenge 2 (SC2) "Food security, sustainable agriculture and forestry, marine, maritime and inland water research and the bioeconomy" stands at € 3.7 Bn. Over 2016 and 2017, a budget of approximately € 877 Mn was made available, of which € 560 Mn on topics related to agriculture (and forestry). Over 140 projects financed under Societal Challenge 2 have already started – some of which also include a GNSS component.

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The EU has also set as its first priority for Rural Development policy for the period 2014-2020 the topic: 'Fostering knowledge transfer and innovation in agriculture, forestry and rural areas'. Agricultural and forestry innovation will therefore also be financed by Rural Development programmes, through several measures supporting, for example, the creation of operational groups, innovation services, investments or other approaches.

In the tables below, an indicative selection of past and current EU-funded projects are presented. The first table shows the projects with a direct GNSS relevance, and describes the key technologies used (e.g. RPAS, DGNSS, GNSS-R) and the solution developed or applied. It is notable – although not unexpected - that research on RPAS continues to attract interest. The PUMPED project, which was funded very recently under the SME Instrument, serves as an example of how innovation with RPAS could create a positioning market by striking a trade-off between cost and accuracy.

Aside from developing new applications or technologies, some of these projects also seek to create the necessary conditions for the wider adoption of GNSS in precision agriculture. This is achieved by activities including **the collection of user requirements** and the **establishment of a User Forum** (e.g. UNIFARM), and the **consolidation of the cost-benefit case for precision agriculture** (e.g. SILF, EU-PLF).

The second table contains projects which do not have an explicit GNSS dimension, but which come from the precision agriculture field. These projects have a specific technological theme (e.g. Future Internet, Robotics, and the Internet of Things) and demonstrate the variety of fields on which precision agriculture draws, as the field enters an integrated and interconnected era. The potential for a GNSS use case has been identified for each project based on the available information.

Table 6: Projects with a GNSS dimension

Technologies used	Project Acronym	Funding	Key Objective(s)	Applied GNSS Solution
RPAS, EGNOS	Fieldcopter	EU FP7 (GSA)	Development of a precision agriculture system based on RPAS mounted with multispectral cameras; proof-of-concept test cases monitoring potato fields and vineyards.	EGNOS augmentation for autonomous navigation of RPAS.
No specific GNSS solution applied in the project	UNIFARM	EU FP7 (GSA)	Collection of user requirements, networking of GNSS initiatives and the establishment of a User Forum for applications of GNSS in agriculture.	No specific GNSS solution applied in the project

Technologies used	Project Acronym	Funding	Key Objective(s)	Applied GNSS Solution
Galileo & EGNOS	GeoPAL	EU FP7 (GSA)	Development of a high-accuracy prototype planning system for agricultural logistics (harvesting, distribution and bio-production).	Galileo and EGNOS for navigation of agricultural machinery to and within fields.
GNSS-R	MISTRALE	EU FP7 (GSA)	Production of soil moisture maps using GNSS-R using a prototype sensor aboard an RPAS platform.	Exploitation of L-Band signal reflectance signatures (from GALILEO) to detect soil moisture.
GPS	e-TRACK	EU FP7 (GSA)	Development GPS-based animal tracking and analysis tools for sophisticated behavioural research on wild and domestic animals.	EGNOS augmentation for animal tracking
GNSS-R	GRASS	ESA	Evaluation of the potential of GNSS-R signals for remote sensing of soil moisture and vegetation biomass	Detecting soil moisture and vegetation biomass using L-Band
GNSS	FarmingTruth	ESA IAP	Provision of a precision agriculture service that furnishes end users (e.g. farmers, growers, agronomists, agricultural consultants, etc.) with a web-based soil and crop information system to enable the optimisation of land production for increasing yield at reduced input cost.	On-line sensor platform and harvester guidance
RPAS, DGNSS	PUMPED	EU EASME	Provision of a low-cost real-time precise navigation solution based on GNSS for RPAS. The accuracy offered by PUMPED will lie between 10cm and 50cm.	Precise navigation by applying DGNSS techniques with low profile GNSS chipsets (often used in RPAS platforms)
GNSS-R	COREGAL	EU H2020	Development of an innovative Galileo based positioning platform enabling low-cost, high-accuracy and unprecedented use of airborne GNSS-Reflectometry (GNSS-R) for biomass retrieval and related and relevant applications as carbon mapping and land management.	Combined Positioning-Reflectometry Galileo Code Receiver for Forest Management
GNSS-R	mapKITE	EU H2020	Build a mature EGNSS enabled prototype of a novel tandem terrestrial-aerial mapping system based on a terrestrial vehicle (TV) and on an unmanned aircraft (UA), both equipped with remote sensing payloads.	EGNOS-GPS/GALILEO-based high-resolution terrestrial-aerial sensing system
GNSS-R	MISTRALE	EU H2020	Demonstrate a service chain in different use cases: pilot projects will be carried out in soil humidity mapping for agriculture (optimizing the water resource management), wetlands and flooded areas (risk management, flood-prone areas, damages evaluation).	Monitoring of Soil moisture and water-flooded areas for agriculture and environment

Table 7: Projects which could potentially be supported by GNSS

Technologies used	Project Acronym	Funding	Key Objective(s)	Applied GNSS Solution
Precision Livestock Monitoring	EU-PLF	EU FP7	Transformation of Precision Livestock Farming (PLF) research concepts into operational tools and the production of a manual (blueprint) for the application of PLF systems in farms.	Livestock position monitoring
Future Internet	Future Farm	EU FP7	Development of integrated Farm Management Information Systems.	Multiple applications as part of an integrated FMIS, including logistic intelligence, animal monitoring, etc.
Future Internet	SmartAgri-Food	EU FP7	Development and testing of integrated Future Internet ICTs in the agri-food and agri-logistics sectors.	GNSS as part of integrated smart FMIS (vehicle tracking, fleet management, logistics).
Robotics	Robofarm	EU FP7	Development of integrated robotic and software platform as an agricultural decision support system.	Positioning, tracking and remote control of robotic agricultural devices.
Precision Livestock Monitoring	ALL-SMART-PIGS	EU FP7	Development of precision livestock farming technologies for European pig farmers.	GNSS as part of a chain traceability system (i.e. creating a verifiable record of product/animal origin).
Cross-cutting	ICT-AGRI	EU FP7	Fostering European research on precision farming and developing a common European research agenda concerning ICT and robotics in agriculture.	Multiple applications through projects funded by ICT-AGRI.
ICT	USER-PA	ERA-NET ICT-Agri	Development and demonstration of an integrated and reliable Precision Agriculture solution for orchards and vineyards using spatial information on irrigation and harvest management.	The positioning of mobile vehicles used for crop sensing.
Smart Farming, Internet of Things	SILF	ERA-NET ICT-Agri	Development of an evaluation platform that demonstrates the potential for an Internet of Things (IoT)-enabled Farm Management Information System, by deploying sensor solutions for (1) lameness detection and (2) ambient environment monitoring.	GNSS technology could complement/augment sensor systems used for monitoring cattle.
Robotics	SWEEPER	EU H2020	Aiming to release to market the first generation of greenhouse harvesting robots, the project will test and validate a robotic harvesting solution for sweet pepper under real-world conditions.	Positioning and navigation of harvesting robot.
Precision Agriculture	TalkingFields	ESA IAP	Aiming to increase the efficiency of agricultural production via precision farming by means of geo-information services.	Positioning and navigation of agricultural vehicles using application maps

Technologies used	Project Acronym	Funding	Key Objective(s)	Applied GNSS Solution
Agri-food Service Platform Hub	Foodie	EU CIP	Designing and creating an open and interoperable geospatial platform hub on the cloud	GNSS-enabled viticulture (project use case) and GNSS-derived data for the data hub
Precise-positioning techniques	AUDITOR	EU H2020	Implementation of novel precise-positioning techniques based on augmentation data in custom GNSS receivers to improve the performance of current augmentation services and reducing costs.	Advanced Multi-Constellation EGNSS Augmentation and Monitoring Network and its Application in Precision
Robotics	GREENPA-TROL	EU H2020	Developing an innovative and efficient robotic solution for Integrated Pest Management in crops, which has the ability to navigate inside greenhouses while performing early pest detection and control tasks in an autonomous way.	Galileo Enhanced Solution for Pest Detection and Control in Greenhouse Fields with Autonomous Service Robots

ANNEX 2: DEFINITION OF KEY GNSS PERFORMANCE PARAMETERS

This Annex provides a definition of the most commonly used GNSS performance parameters, coming from [RD45]. and is not specifically focusing on the Agriculture community.

Availability: the percentage of time the position, navigation or timing solution can be computed by the user. Values vary greatly according to the specific application and services used but typically range from 95-99.9%. There are two classes of availability:

- System: the percentage of time the system allows the user to compute a position – this is what GNSS Interface Control Documents (ICDs) refer to
- Overall: takes into account the receiver performance and the user's environment (for example if they are subject to shadowing).

Accuracy: the difference between a true and computed position (absolute positioning). This is expressed as the value within which a specified proportion of samples would fall if measured. Typical values for accuracy range from tens of meters to centimetres for 95% of samples. Accuracy is typically stated as 2D (horizontal), 3D (horizontal and height) or time.

Continuity: ability to provide the required performance during an operation without interruption once the operation has started. Continuity is usually expressed as the risk of a discontinuity and depends entirely on the timeframe of the application (e.g. an application that requires 10 minutes of uninterrupted service has a different continuity figure than one requiring two hours of uninterrupted service, even if using the same receiver and services). A typical value is 1x10-4 over the course of the procedure where the system is in use.

Integrity: the measure of trust that can be placed in the correctness of the position or time estimate provided by the receiver. This is usually expressed as the probability of a user being exposed to an error larger than alert limits without warning. The way integrity is ensured and assessed, and the means of delivering integrity-related information to the user are highly application dependent. For safety-of-life-critical applications such as passenger transportation, the "integrity concept" is generally mature, and integrity can be described by a set of precisely defined and measurable parameters. This is particularly true for civil aviation. For less critical or emerging applications, however, the situation is different, with an acknowledged need of integrity but no unified way of quantifying or satisfying it. Throughout this report, "integrity" is to be understood at large, i.e. not restricted to safety-critical or civil aviation definitions but also encompassing concepts of quality assurance/quality control as used by other applications and sectors.

Robustness to spoofing and jamming: robustness is a qualitative, rather than quantitative, parameter that depends on the type of attack or interference the receiver is capable of mitigating. It can include authentication information to ensure users that the signal comes from a valid source (enabling sensitive applications).

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In this document, characterisation of the robustness against GNSS spoofing is made as follows:

1. Identification of the different types of attacks using Humphrey's spoofing threat continuum
2. For each **type of attack**, assessment of:
    - The **cost** of attack
    - The **time** to put the attack in place
    - The **capacity** needed to implement the attack
    - Deduction form the information here above of the possible **profile of attackers**

Low, Medium, High, Very High susceptibly to spoofing are defined as follows:

Note: for some users, robustness may have a different meaning, such as the ability of the solution to respond following a severe shadowing event. For the purpose of this document, robustness is defined as the ability of the solution to mitigate interference or spoofing.

Indoor penetration: the ability of a signal to penetrate inside buildings (e.g. through windows). Indoor penetration does not have an agreed or typical means of expression. In GNSS, this parameter is dictated by the sensitivity of the receiver, whereas for other positioning technologies there are vastly different factors that determine performance (for example, availability of Wi-Fi base stations for Wi-Fi-based positioning).

Time To First Fix (TTFF): a measure of a receiver's performance covering the time between activation and output of a position within the required accuracy bounds. Activation means subtly different things depending on the status of the data the receiver has access to:

- Cold start: the receiver has no knowledge of the current situation and thus has to systematically search for and identify signals before processing them – a process that typically takes 15 minutes.

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Susceptibly to spoofing	Types of attacks	Cost of attack	Time to put in place	Capacity	Profile of attackers
Low	Plug and play	> €10	A few hours	Very little	End users Criminal
Medium	Record and replay (using SDR)	Several €100s	Weeks	Limited	End users Criminal
High	Non-synchronised attack (can be done with SDR)	Between €1000 and €100 000s	A few months	Significant	Organised crime
Very High	Synchronised attack	More than €1000 000	From 6 months to a year	Formidable	Hostile nations

- Warm start: the receiver has estimates of the current situation – typically taking 45 seconds.
- Hot start: the receiver knows what the current situation is – typically taking 20 seconds.

Latency: the difference between the time the receiver estimates the position and the presentation of the position solution to the end user (i.e. the time taken to process a solution). Latency is usually not considered in positioning, as many applications operate in, effectively, real time. However, it is an important driver in the development of receivers. This is typically accounted for in a receiver but is a potential problem for integration (fusion) of multiple positioning solutions or for high dynamics mobiles.

GNSS IS THE KEY ENABLING TECHNOLOGY OF A NUMBER OF APPLICATIONS THAT SUPPORT FARMERS TO INCREASE THE PRODUCTIVITY AND PROFITABILITY

Power consumption: the amount of power a device uses to provide a position. The power consumption of the positioning technology will vary depending on the available signals and data. For example, GPS chips will use more power when scanning to identify signals (cold start) than when computing position. Typical values are in the order of tens of mW (for smartphone chipsets).

ANNEX 3: GNSS USE IN AGRICULTURE

GNSS is the key enabling technology of a number of applications that support farmers to increase the productivity and profitability of agricultural activities (precision agriculture) and improve the management of their farms (agri-logistic applications), whilst also complying with the current legislative and regulatory framework. Through the provision of the precise location of farming equipment, and frequently combined with other technologies such as GIS, remote sensing (through satellites or RPAS) and machine vision, GNSS allows the accurate steering of tractors and the minimisation of pass-to-pass overlaps, the precise application of agricultural inputs at different rates throughout the field and the retrieval of geo-localised data that can enable more efficient yield monitoring.

Based on the scope of each application different GNSS performance parameters, including accuracy, reliability, availability, authenticity and coverage become relevant. Amongst them, high accuracy is the most fundamental and universally sought. Just how high this accuracy must depend on the specific requirements of the farming process in question and the enabling technologies to achieve it. Given that satellite radio signals processed by receivers on the ground can be affected by a number of factors (atmospheric interference, configuration of the satellites and multipath effects, operating environment, time estimation uncertainties, etc.) irrespective of the system used (i.e. GPS, Galileo, GLONASS, etc.), the deployment of differential correction services for improved accuracy becomes necessary. Thus, differential correction systems calculate GNSS errors at a known location (by utilising a base station receiver or network of receivers) and transmit, in real-time, the corrections to "roving" receivers that are mounted on agricultural equipment, either directly or through communication channels (incl. satellites). Taking this into account, agricultural applications rely on four main types of solutions (listed in order of increasing accuracy): Uncorrected GNSS-based (metre), SBAS-based (sub-meter), commercial DGNSS (up to 5cm) and Real-Time Kinematic (up to 2 cm). These can be grouped in three accuracy regimes as summarised below:

- **Low accuracy:** Applications such as asset management, geo-traceability and livestock tracking require an accuracy of a few meters (2-5m) and are typically delivered by standalone GNSS or SBAS-enabled receivers.
- **Medium Accuracy:** Manual tractor guidance for operations such as spraying, spreading and harvesting of bulk crops, as well as field measurement and boundary mapping applications, require the sub-metre accuracy (10-30 cm pass-to-pass, 60-80 cm absolute) enabled by augmentation systems such as EGNOS. DGNSS solutions, typically delivering pass-to-pass accuracy from 10 to 20 cm, can be also considered in this category.
- **High Accuracy:** Automatic steering of tractors and operations such as planting and sowing require an accuracy of a few centimetres (2-10cm), provided by Real Time Kinematic (RTK). Emerging PPP solutions can also deliver sub-decimetre accuracy but at the expense of extended convergence time (typically over 30 minutes).

It is important to note that in the context of precision agriculture two types of accuracy are relevant:

- **Pass-to-pass accuracy** represents the relative accuracy between adjacent, parallel passes made by farm machinery carrying a GNSS receiver within 15 minutes from one another.
- **Year-to-year or long-term accuracy (also referred to as GNSS drift)** is defined as the accuracy of the GNSS receiver over time, taking into account changes in the satellite constellation pattern, the operating environment and satellite data errors.

The positioning accuracy specifications of commercial devices typically refer to pass-to-pass accuracy. However, year-to-year accuracy or GNSS drift becomes particularly relevant when performing farming operations which require coming back to exact locations at different times (e.g. controlled traffic, strip tillage, etc.). Both types of accuracies are mainly affected by the type of differential correction used, RTK being the least affected by GNSS drift. The specifics of different solutions mentioned above are presented below.

Real-Time Kinematic (RTK)

Real-Time Kinematic solutions enable highly-accurate, highly-repeatable positioning in the vicinity (typically 10-20km) of a base station receiver placed on a - ideally immobile - mount. The main principle behind RTK services relies on the assumption that positioning errors (due for example to clock bias, atmospheric delays, satellite orbital errors, etc.) computed at the base station under local field conditions, are the same as those occurring for the mobile receiver (rover). RTK utilises a real-time communication channel (usually short-range radio) to transmit the corrections from the base station, whose location is well known, to the rover thus eliminating the errors that typically tamper standalone positioning. The base station broadcasts its well-known location together with the code and carrier measurements at L1 and L2 frequencies for all in-view satellites. This information allows the rover equipment to fix the phase ambiguities and determine its location relative to the base with precision up to 2 cm. By adding up the location of the base, the rover is positioned in a global coordinate framework.

GNSS ALLOWS THE ACCURATE STEERING OF TRACTORS AND THE MINIMISATION OF PASS-TO-PASS OVERLAPS

The corrections are as accurate as the known location of the base station and the quality of the base station's satellite observations. Also important is the operating environment (to minimise environmental effects such as interference and multipath) and the quality of the receivers (rover and base station). In addition, the actual accuracy achieved at the rover receiver is a function of its distance from the base station. To alleviate this limitation, networks of several widely spaced base stations have been deployed, especially in more countries of advanced maturity. In fact, RTK networks are the preferred option in North America, where commercial and public initiatives have been long established. Examples range from RTK clusters and publically run RTK networks in the US[57], to commercial solutions in the EU (e.g. UK's Leica SmartNet, establishment of base stations supported by farming organisations and government in Holland, etc.)

The landscape of RTK is changing with

- The proliferation of RTK GNSS receiver "boards" such as the Trimble BD series, Novatel OEM series, Hemisphere GNSS P series, and Septentrio AsteRx series.[58]
- Massive uptake of RTK solutions in fast-growing w.r.t precision agriculture markets such as China - which lies in the so-called GNSS hotspot of satellite visibility.
- A significant decrease in the price of RTK GNSS receivers, due to a congested market and the competitive pressure from emerging PPP solutions (described next).

These elements are driving, according to some experts[59], the trends towards the commodification of high-precision GNSS receivers, in particular, low-cost dual frequency (L1/L5) receivers capable of cm-level horizontal/vertical precision which should become widely available and thus enable the proliferation of RTK.

Precise Point Positioning (PPP)

Unlike RTK, Precise Point Positioning (PPP), employs readily available satellite orbit and clock correction data, generated from a network of global reference stations, to perform absolute positioning using measurements from a single GNSS receiver. The corrections are delivered to the end user via satellite or over the internet ensuring thusly worldwide coverage. PPP can achieve decimetre-level accuracy without the need for a base station in the proximity. This comes however at a price; PPP requires a rather long time (15-30 min) resolving any local biases such as the atmospheric conditions, multipath environment and satellite geometry, to converge to decimetre-level accuracy. However, a number of solutions are emerging that can mitigate this problem, from the more powerful computation in chipsets, the use of several constellations and the use of more than two frequencies. The most common and optimized technique in terms of bandwidth for real-time PPP is to send orbits and clock corrections to the navigation message, allowing the reconstruction of the accurate values in the receiver.

Despite the challenges of delivering PPP solutions - especially in a real-time environment, PPP solutions are currently seen as a viable alternative to DGNSS solutions and are trending amongst farmers who want better accuracy than that provided by SBAS and lesser investment than that required

57 http://gpsworld.com/finally-a-list-of-public-rtk-base-stations-in-the-u-s/
58 http://gpsworld.com/rtk-gnss-receivers-a-flooded-market/
59 http://www.apsg.info/Resources/Documents/Presentations/APSG33/Eric_Gakstatter_APSG_Apr_7_2015.pdf

for RTK. A prime example of well-performing PPP solution is Trimble's CenterPoint RTX which regularly achieves less than 4 cm accuracy for users (but initialisation time ranges from 5-30 min). Several other vendors offer PPP solutions including OmniSTAR, VERIPOS, TerraStar, StarFire, etc. Thus, in the context of centimetre accuracy applications, while RTK remains the premium option and offers immediate solution convergence, the minimal equipment needs and global accessibility make PPP an interesting alternative[60].

PPP-RTK

PPP-RTK solutions constitute an extension to the PPP concept by providing single-receiver users with information enabling integer ambiguity resolution, thereby reducing convergence times as compared to that of standard PPP. Thus, alongside the precise satellite clocks, orbits and phase bias, PPP-RTK makes use of local/regional/national RTK networks to provide users with ionospheric and tropospheric delay corrections, allowing them to perform integer resolution of ambiguities and achieve cm-level accuracy in significantly reduced time. This is typically in the range of 1-10 minutes, but in certain configurations, it can even be done within seconds[61]. An additional advantage as compared to RTK-only is that of sending fully computed corrections to the "rover" and eliminating certain local errors that appear on the local reference stations (e.g. multipath). Several PPP-RTK solutions[62] are currently under deployment building on different methods[63], thus underlining the market potential for this approach. In the context of agriculture, such solutions may become important for applications where autonomous vehicles are involved.

DGNSS

Differential-GNSS services encompass techniques used to enhance accuracy, reliability and availability of GNSS information through a network of ground-based reference stations. As with RTK, which is essentially an advanced DGNSS solution based on the use of carrier measurements, the corrections calculated at a reference station of known-location are transmitted via communication channels to the users. DGNSS solutions able to support multiple GNSS systems such as GPS, and GLONASS are deployed worldwide. Commercial DGNSS solutions are widely available and provided by several vendors including OmniSTAR, VERIPOS, etc. However, with SBAS-solutions becoming more widely available, RTK fees decreasing and PPP solutions emerging the future of DGNSS seems cloudy.

Satellite-based Augmentation Systems (SBAS)

SBAS-based solutions are becoming increasingly available in precision agriculture applications, frequently being the preferred option for farmers entering the PA market. SBAS systems provide services for improving the accuracy, integrity and availability of the basic GNSS signals. This is achieved through a ground infrastructure consisting of reference stations receiving the data from the GNSS satellites and a Processing Facility Centre that computes the integrity, corrections and ranging data forming the SBAS SIS. This is then transmitted or relayed through geostationary satellites back to users on the ground. Apart from integrity assurance, this correction service increases the positioning accuracy at end-users receivers (getting both the primary and the SBAS signals) to sub-metre level.

Being widely available over continental scales (EGNOS over Europe and North Africa, WAAS over North America, etc.), free of subscription fees or additional investment costs, SBAS-based solutions are widespread amongst farmers, requiring accuracy to sub-metre level. Almost 80% of GNSS receivers used in agriculture are SBAS-equipped. Along with the four operational SBAS systems (EGNOS, WAAS, MSAS and GAGAN), South Korea's KASS, China's BeiDou SBAS, Russia's System for Differential Corrections and Monitoring (SDCM), and the West African Agency for Aerial Navigation Safety in Africa and Madagascar (ASECNA) SBAS are under various stages of deployment.

In Europe, EGNOS is complemented by EDAS that disseminates EGNOS data through the Internet (instead of the EGNOS SIS). EDAS could enhance the availability and continuity of GNSS signals for agricultural activities, at a minimal additional cost in areas with good internet connectivity.

Standalone / Uncorrected GNSS

The dawn of the multi-constellation era, coupled with advancements in GNSS signal structure and the increased availability of multi-frequency options, contributes to increased accuracy and availability of GNSS signals worldwide. More specifically, agricultural actors demanding

60 See for example http://www.novatel.com/tech-talk/velocity/velocity-2015/ppp-cultivating-profits/#ppp-matching-performance-to-application-requirements-in-the-field
61 See for example Wübbena 2016
62 See for example Odijk 2016 for the case of Australia.
63 For a review see for example Teunissen 2014.

high-accuracy solutions will greatly benefit by the emergence of multi-frequency receivers. This trend is well exemplified by the recent procurement for the development of multi-frequency, multi-purpose antennas for Galileo (e.g. L1/E1, L2, L5/E5) under the EUSPA's Fundamental Elements. Similarly expected R&D in high-end receivers' core advancements and User Terminals under the same instrument should yield promise for high-accuracy agricultural applications too.

Zooming in from this broad picture, this report will present the state-of-play, main characteristics, adoption level and related challenges of the various GNSS-enabled solutions classified under precision agriculture and agri-logistic applications. A more elaborate analysis of GNSS user requirement drivers and limitations, as well as policy and regulatory framework considerations, is also covered in this chapter.

ANNEX 4: PROSPECTIVE USE OF GNSS IN AGRICULTURE

The key technological trends propelling the use of GNSS in agriculture are characterised by

- Affordable and reliable SBAS solutions opening up markets for entry-level users and paving the way for the adoption of more advanced solutions
- The increased availability of GNSS signals as a result of the multi-constellation era, enabling better performance and reliability of application in attenuated environments
- The proliferation of dual frequency receivers and authentication/high-accuracy options provided by Galileo HAS, supporting a number of existing and future applications
- The reduced price for RTK and DGNSS solutions and the emergence of PPP solutions, driving their wider adoption by more farmers
- Fusion and integration with other technologies within whole-farm management solutions (IFM or FMIS)

Taking these top-level considerations into account, the main technological trends and prospects for the use of GNSS in agriculture are briefly presented below.

Emerging multi-frequency and multi-constellation solutions

The advent of the multi-constellation era has brought end-users across practically all agricultural applications, several important benefits including increased availability (especially in attenuated environments), faster ambiguity resolution and better coverage (relevant especially for northern latitudes). Recalling that the most demanding agricultural applications (e.g. automatic steering) require double-frequency receivers, the introduction of Galileo High Accuracy Service (E6) will allow end-users to benefit from triple frequency solutions. These are expected to significantly reduce convergence time for PPP and differential techniques. In this context, particular importance lays on the fact that GPS will not support legacy L2 (P/Y) signals beyond 2020. This means a migration to L2C or L5 capable equipment to guarantee high-precision performance.

Galileo High Accuracy Service novelties

Various analyses have shown that the Galileo High Accuracy Service E6-B signal is well suited for transmitting PPP information, allowing an adequate update rate for the achievement of centimetre level accuracy. In addition, as the HAS allows for the transmission of different bits from different satellites, the total bandwidth can be highly increased leading to a better performance that, when combined with other factors may reduce the PPP receiver convergence time. The value of the potential TTC improvement expected by HAS is also underlined in the interviews carried out in the process of putting this report together [RD41]. Moreover, HAS will offer triple frequency, enabling faster convergence time and accuracy comparable to RTK. Finally, the authentication feature of Galileo HAS may be particularly interesting in sectors underpinned by regulatory considerations and for the validation of documentation processes (see [RD41]).

RTK vs. PPP uptake

The landscape of RTK is changing with:

- The proliferation of RTK GNSS receiver "boards" such as the Trimble BD series, Novatel OEM series, Hemisphere GNSS P series, and Septentrio AsteRx series.[64]
- Massive uptake of RTK solutions in fast-growing markets such as China - which lies in the so-called GNSS hotspot of satellite visibility.
- The development of active and passive reference stations and network RTK reference station networks by several national mapping agencies and commercial vendors
- A significant decrease in the price of RTK GNSS receivers, due to a congested market and the competitive pressure from emerging PPP solutions (described next).

These elements are driving, according to some experts[65], the trends towards the commoditization of high-precision GNSS receivers, in particular, low-cost dual frequency (L1/L5) receivers capable of cm-level horizontal/vertical precision which should become widely available and thus enable the proliferation of RTK for a given range of high-accuracy applications. For example, in 2014 GNSS RTK price ranged from US$6,500 to US$25,000, whilst the trend of decreasing prices continues[66].

At the same time, and despite the challenges in delivering PPP solutions - especially in a real-time environment, they are currently seen as a viable alternative to DGNSS solutions and are trending amongst users who want good accuracy but at a lesser investment than that required for RTK[67]. A prime example of well-performing PPP solution is Trimble's CenterPoint RTX which regularly achieves less than 4 cm accuracy for users (but initialisation time ranges from 5-30 min). Several other vendors offer PPP solutions including OmniSTAR, VERIPOS, TerraStar, StarFire, etc. Thus, in the context of centimetre accuracy applications, while RTK remains the premium option and offers immediate solution convergence, the minimal equipment needs and global accessibility make PPP an interesting alternative.

Integrated Farm Management Solutions - combining GNSS with complementary technologies

One of the most clearly emerging trends in technology-driven agriculture is that of integrating data and technologies in all-around solutions. A number of complementary to GNSS solutions have arisen, ranging from satellite remote sensing techniques (which are actually well established in certain applications) and the use of RPAS for a number of farming practices to the deployment of Big Data analytics, Internet-of-Things and Future ICT solutions in a highly digitised and interconnected framework.

THE ADVENT OF THE MULTI-CONSTELLATION ERA HAS BROUGHT END-USERS ACROSS PRACTICALLY ALL AGRICULTURAL APPLICATIONS SEVERAL IMPORTANT BENEFITS

Thus, the deployment of different technologies capturing data on the spatial and temporal variability of crops across farms enables informed decision-making and management strategy elaboration for farmers. However, intensive data collection is not necessarily confined to the strict boundaries of a particular farm; instead, the wealth of information collected and tools developed in one farm can provide valuable inputs to handle and apply information properly for any type of farm in any region. This information-driven approach can be used to help improve crop management strategies and proof of compliance through documentation. In this context, integrated farm management solutions combine real-time modelling and data collection (through different sectors, with expert systems in line with guidelines from a recommended management strategy, e.g. organic, integrated crop management (ICM), integrated pest management (IPM), factored risk etc., as well as legal guidance (such as health and safety and environmental protection). This integrated approach enables farm advisers to develop tailored practices for individual farms or groups thereof and eventually help farm or crop managers make better decisions. GNSS constitutes a key component

64 http://gpsworld.com/rtk-gnss-receivers-a-flooded-market/
65 http://www.apsg.info/Resources/Documents/Presentations/APSG33/Eric_Gakstatter_APSG_Apr_7_2015.pdf
66 http://gpsworld.com/centimeter-level-rtk-accuracy-more-and-more-available-for-less-and-less/
67 The PPP solutions' cost-effectiveness is particularly applicable to areas not covered by CORS networks

of such integrated management systems since it enables the "site-specific" dimension of the collected data that is then infused into management strategies.

However, important challenges in the successful implementation of integrated farm management (IFM) solutions exist, related primarily to the difficulty of extracting useful information from the various collected data, interoperability and data format standardisation issues, and connectivity between the various data sources. That said, the future of IFM looks promising; according to an interviewee from John Deere [RD41] the uptake in Europe is currently (2016) at the level of 10% and expected to rise to 40 % especially in high-end markets like Germany.

A short description of the most important technologies that support this integrated solution framework is provided below.

Remote Sensing via satellites

Remote sensing techniques have been and can further contribute to providing timely and accurate data on a number of aspects related to agricultural production, spanning from yield mapping and yield forecasting, to monitoring weather and climatic variables, and from soil mapping and land cover changes.

ONE OF THE MOST CLEARLY EMERGING TRENDS IN TECHNOLOGY-DRIVEN AGRICULTURE IS THAT OF INTEGRATING DATA AND TECHNOLOGIES IN ALL-AROUND SOLUTIONS

In the context of remote sensing, agricultural monitoring relies on a combination of satellite imagery, meteorological data, agrometeorological and biophysical modelling as well as statistical analyses. Remote sensing via satellites is particularly fit for gathering information over large areas with high revisit frequency. The utilisation of high to low resolution, multispectral optical sensors allows the monitoring of key parameters pertaining to crop and vegetation health, including crop type and area, Leaf Area Index or Normalised Difference Vegetation Index (NDVI). By deploying assimilation models key information can be derived (e.g. evapotranspiration rates) contributing to the optimisation of irrigation practices and fertiliser utilisation. Furthermore, multi-temporal SAR data are increasingly used for the continuous monitoring soil moisture content and soil composition. Several other applications are emerging owing to the availability of better optical (e.g. classification of crop species, soil texture, soil content on certain nutrients) and radar sensors (e.g. fresh and dry biomass monitoring). Copernicus, offering vast amounts of free and open data via the Sentinel missions, will significantly contribute to further advancing the use of remote sensing techniques in precision agriculture. For example, Sentinel 2 provides a 10-metre resolution that can be relevant even to individual land parcels, whilst its revisit time stands at 5 days making it highly relevant for crop dynamics monitoring. Sentinel-1 SAR mission enables remote sensing regardless of the weather conditions (i.e. cloud masking). In addition, Copernicus will support enhanced delivery of weather or climate forecast related information that can prove particularly useful to farmers.

Apart from Copernicus and other missions that initiated the use of Earth Observation satellites for agriculture (Landsat-1) a number of initiatives exist at a regional, continental or even global scale. Indicatively, a number of systems exist providing crop monitoring, alerts and forecasts:

- The US FAS Global Agricultural Monitoring Project;
- FAO's Global Information and Early Warning System (GIEWS);
- JRC's MARS providing EU agricultural production estimates and food security assessments;
- The Crop Watch Program at the Institute of Remote Sensing of the Chinese Academy of Sciences

In conjunction with GNSS, remote sensing is used in key precision agriculture applications such as Biomass Monitoring and Soil Sampling, especially with regard to the creation of prescription maps and crop management zones. In the broader sense of remote sensing via satellites, an emerging solution lies in the utilisation of GNSS reflectometry for a number of applications (see chapter 7 on the ESA GRASS project for more details).

Remotely Piloted Aircraft Systems (RPAS)

The utilisation of RPAS (or else UAVs or drones) in precision agriculture marks and an ongoing trend that is characterised by a number of dedicated R&D efforts, an increasing number of commercial solutions being launched by both established players (e.g. Trimble and DJI in China), and a strict regulatory framework constraining their rapid uptake. RPAS is used either as an alternative to high-resolution imagery from satellites or as farming equipment (e.g. crop-sprayers). The range of applications in which RPAS have been progressively introduced covers amongst else surveying flights in the planning stage of an agricultural project, yield mapping, crop-cutting records and field management. Being less susceptible to cloud conditions RPAS are able to provide high-resolution imagery that can be made available to farmers either in near real-time or post-processed. Recent indicative examples highlighting the increased penetration of RPAS in the commercial market include the unveiling of the Chinese company DJI - arguably the world leader in camera drones - of their first agriculture

targeted crop-spraying drone. The Argas MG-1 can carry 10 kilograms of liquid and can cover between 7 to 10 acres per hour, operating at centimetre accuracy and offering 40 times the efficiency of the manual application. Another example includes Trimble's RPAS, that can fly over crops and fields and with a right camera collect relevant remote sensing imagery that helps farmers make decisions about when and where and how much fertiliser to apply.

In Europe, the FieldCopter project demonstrated the combination of small sensors onboard unmanned vehicles for fast turn-around times, where the farmer had access to the spatial products showing water and nutrient stress levels in grapes and potatoes a few hours after the drone had flown the field.

As regulation formulation progresses, and RPAS technology advances, the trend for their adoption in precision agriculture activities will be increasingly relevant. In this context, and in particular as far the Beyond-the-line-of-sight flights are concerned, GNSS will be a key enabling technology both in terms of continuously available signals and, of course, high accuracy of operations.

Robotics

Another ongoing trend concerns automation and the increased use of robots on a number of farming practices. Apart from RPAS referred to above, fully autonomous or robotic field machines are increasingly employed in small-scale, high profit-margin agriculture such as wine grapes, nursery plants and some fruits and vegetables. In Europe, research projects such as Robofarm, Clever Robots for Crops and Sweeper, have been carrying out dedicated R&D on various use cases of robot use in farming practices. In general, roboticised precision farming promises to increase yields by optimising growth and harvesting processes, while helping to lower fertiliser and pesticide usage and improved soil quality through more targeted interventions. The autonomous operations performed by robots on the field are enabled by automatic steering technologies and high-precision positioning offered by GNSS solutions. Introduction of robotic solutions is led by Japan - having a strong global position in robotics in general, whilst autonomous machines are increasingly used in the US too, and in particular in California where high-value crops are grown.

IoT, Big Data and Future ICT

Connecting all devices used in a farm within the IoT concept is another emerging trend of particular prominence. By combining different technologies and fast internet access, farmers will be able to obtain results from crop sensing activities on (near)-real time, supporting them in farm management decision-making. In this context, big data analytics will support processing large numbers of site-specific, geo-referenced data from the various sensors and enable integrated decision support tools. IoT, Big Data and Future ICT will be a core part of "Smart Farming" solutions in the (near) future.

Despite the increasing trend for such integrated solutions, several challenges exist ranging from the need to develop new business models on data management, developing sharing and open-data sources for PA, addressing data ownership issues and building IT infrastructure (cloud solutions) for data storage. Furthermore, there is currently an "intelligence gap" related to the interpretation of the various data collected in the field of actionable information that is useful for the farmers (see [RD41]).

ANNEX 5: LIST OF ACRONYMS

AEF	Agricultural Industry Electronics Foundation
AET	Agricultural Engineering and Technologies
ASECNA	Agency for Aerial Navigation Safety in Africa and Madagascar
AUTH	Authentication - referring to Galileo Signal Authentication Service
BSE	Bovine spongiform encephalopathy
CAGR	Compound Annual Growth Rate
CAP	Common Agricultural Policy
CEMA	Comité Européen des groupements de constructeurs du machinisme agricole
CIP	Competitiveness and Innovation Framework Programme
COGECA	General Committee for Agricultural Cooperation in the European Union
CONNECT	Communications Networks, Content and Technology
COPA	Committee of Professional Agricultural Organisations
CORS	Continuously Operating Reference Stations
CTF	Controlled Traffic Farming
DGNSS	Differential GNSS
EASME	Executive Agency for Small and Medium-sized Enterprises
EGNOS	European Geostationary Navigation Overlay Service
EGNSS	European GNSS
EIP	European Innovation Partnership
ENV	Refers to European Commission's DG Environment
ESA	European Space Agency
FAS	Farm Advisory Services
FMIS	Farm management information systems
G2G	Galileo 2nd Generation
GIEWS	Global Information and Early Warning System
GIS	Geographic Information System
GLONASS	Globalnaya Navigazionnaya Sputnikovaya Sistema
GNSS	Global Navigation Satellite System
GPRS	General Packet Radio Service
GPS	Global Positioning System
GROW	Refers to European Commission's DG Internal Market, Industry, Entrepreneurship and SMEs
GSA	European GNSS Agency
HAS	High Accuracy Service
HGCA	Home-Grown Cereals Authority (UK)
HPAI	Highly pathogenic avian influenza
IACS	Integrated Administration and Control System

IAP	Integrated Applications Programme (ESA)
ICM	Integrated crop management
ICT	Information and Communications Technology
IPM	Integrated pest management
JRC	Joint Research Centre
KASS	Korean Augmentation Satellite System
LBS	Location-Based Service
LIDAR	Light Detection And Ranging
LPIS	Land Parcel Identification System
MKD	Market Development (within EUSPA)
MSAS	Multi-functional Satellite Augmentation System
NDVI	Normalised Difference Vegetation Index
NVZ	Nitrate Vulnerable Zones
OEM	Original Equipment Manufacturer
OTS	On the Spot
PLF	Precision Livestock Farming
PNT	Positioning, navigation, and timing
PPP	Precise Point Positioning
RDP	Rural development programmes
RPAS	Remotely Piloted Aircraft System
RTK	Real-Time Kinematic
SAR	Synthetic-aperture radar
SAS	Signal Authentication Service
SBAS	Satellite-based augmentation system
SDCM	System for Differential Corrections and Monitoring
SIS	Signal in Space
SME	Small and Medium-sized Enterprise
SOM	Soil Organic Matter
TTC	Time-to-Convergence
UCP	User Consultation Platform
VHF	Very high frequency
VRA	Variable Rate Application
VRT	Variable Rate Technology
WAAS	Wide Area Augmentation System
WGS84	World Geodetic System 1984
WLAN	Wireless Local Area Network

ANNEX 6: UPDATES FOLLOWING THE USER CONSULTATION PLATFORM 2018

As per EUSPA document reference GSA-MKD-AGR-UREQ-250281 available here.

ANNEX 7: UPDATES FOLLOWING THE USER CONSULTATION PLATFORM 2020

As per EUSPA document reference EUSPA-MKD-AGR-UREQ-250281 available here.

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