DELIVERABLE 3.1

State of the Art in GNSS Solutions for Agriculture

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Abstract:	The current document contains a methodology of the GNSS system development process in the context of AgriBIT project. In this framework, GNSS exploitation in modern agricultural systems has been described, as well as several field operations where GNSS is being used, accompanied by distinct connectivity and compatibility requirements of the system with respect to the developed Use Cases. Furthermore, a wide survey has been conducted and is presented in this document, regarding the available existing commercial GNSS solutions and funded research activities, aiming to act as a baseline for the AgriBIT GNSS system. Finally, user requirements described in D2.1 of the project were compared to the aforementioned survey, in order to achieve the development of a high-end valuable GNSS tool that will assist farmers in daily agricultural practices.		

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Executive Summary

GNSS systems have widely been used in agriculture during the last decades. This use has significantly simplified the exercise of several agricultural practices, while has also played a key role in the farmers' fatigue reduction. This modernization of agriculture has allowed an increase of the farmers' income with simultaneous benefits for human and the environment. However, during the development of a commercial GNSS system, user requirements should be thoroughly monitored, as in AgriBIT case, in order to allow the development of a useful and valuable tool for farmers.

In the current document, the user requirements monitored and described in D2.1 of the project, are used in order to be parallelized with the existing available commercial GNSS solutions. This methodology ensures the smooth and uninterrupted GNSS development and aligns the actual demands of end-users with the final tool that will be developed. This way, minimization of future amendments of the system will occur, along with targeted and concrete characteristics of the system.

In this context, commercial products and research outputs were investigated, based on several aspects, allowing an in depth understanding of the market trends. More specifically, a list of over 39 of commercial products that show possible compliance with user needs and over 78 EU-funded projects (18 of which are still ongoing) was created in order to serve as a pool of knowledge, for further investigation. Apart from that, system specifications with respect to connectivity and data sharing, along with reliability of the system, were properly gleaned based on the corresponding outputs derived by the user requirements analysis.

Additionally, 8 developed Use Cases that refer to different purposes and actions in agriculture (recording, monitoring, mapping, sampling, tracking, navigation, positioning, and VR applications) were presented. Finally, the original prototype of the GNSS receiver developed by RFSAT was presented, in order to provide a preliminary introductory demonstration of the AgriBIT system.

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1. Introduction

Eliciting user requirements' is of paramount significance in the process of developing products for wide market launch [1]. In terms of reliability, after user requirements' analysis, the final results are expected to be more robust and the risk during commercialization is expected to be lower, in the case of integrating the outputs of the user requirements' investigation analysis. Regarding the architecture, more concrete and useable results are expected to come up for the under development product. As the main objective of AgriBIT is to produce a valuable tool to be used by farmers, their needs were widely monitored during the surveys conducted in the framework of D2.1 "AgriBIT user requirements" in 3 distinct areas of Europe.

Based on the existing knowledge, the highly expressed interest regarding user requirements in several aspects, has resulted to their classification by using Deep Learning [2]. In addition to this, ISO standards have also been developed to identify and define different types of user requirements [3]. The aforementioned results, prove the need for proper exploitation of validated user requirements. These aspects, are seriously taken into consideration in AgriBIT case, aiming to develop a valuable GNSS system for agriculture. Thus, the current document constitutes a report on the outputs of Task 3.1 of the project "Analysis of SoA in GNSS and Base Solution Architecture".

2. Methodology

In this context, a review of the existing commercial solutions has been performed under Task 3.1 “Analysis of SoA in GNSS and Base Solution Architecture”, which in addition with the validated user requirements, will shape the new product that will be launched, aiming to cover the major needs of the various potential end-users. Similar approaches have been carried out for relative subjects, such as in satellite soil moisture applications [4].

In general, scientific publications indicate the development of different conceptual models regarding user requirements. More specifically, notations for user requirements can either be use cases (UC) or use stories (US) [5]. In the occasion of AgriBIT project, UC scenarios have been built, aiming to investigate several aspects of the systems’ use by its users. Main purpose was achieving compliance of positioning and localization information with the practical need of end-users. This harmonization is expected to play a crucial role in the development of the system’s and GNSS sub-system’s architecture in compliance with the user requirements within Task 3.2 “Architecture, Baseline Prototype and Applied R&D” and in the customization options to various types of agricultural applications within Task 3.3 of the project “Architecture, Baseline Prototype and Applied R&D”. After the system’s development and further enabling of customization features, validation of the system will take place under Task 3.4 “Formal Technical Validation of GNSS sub-system”.

3. GNSS technology

A Global Navigation Satellite System (GNSS) is a satellite configuration/constellation, which provides coded satellite signals that are processed by a GNSS receiver to calculate position, velocity, and time [6]. A significant advantage of the GNSS system, is that there is no limit to the number of users allowed to utilize its technology, making it available for anyone to use around the world.

In 1978, the first satellite for navigation systems was launched by the United States. This allowed the development of a fully operational constellation of 24 satellites known as the NAVSTAR Global Positioning System during the early 90s. Nowadays, this system is known as the Global Positioning System (GPS) and is composed by 31 satellites that constitute its constellation. Apart from the U.S.A., several countries have attempted to launch such systems. Their attempts are presented in detail in paragraph 3.2 of the current document.

In Europe, EUSPA is the European Union Agency for the Space Programme. It was initially created in 2004 as European Global Navigation Satellite Systems Supervisory Authority (GSA), but is in its current form since 2021. EUSPA’s main objective is to ensure safe and secure European satellite navigation services, while also promote the commercial use of Galileo systems and EGNOS.

Along with that system, GNSS will be explored in greater depth, and similar solutions from other countries shall also have a brief mention. Various milestones for accuracy and ease-of-use will be presented as well.

3.1. General aspects

GNSS: Global Navigation Satellite System

A composite system that is meant to enable client devices, i.e. consumers of the service, to ascertain their own position on the globe. On the service provision side, the system consists of a space segment and a control segment (based on Earth):

3.1.1. Constellation of artificial satellites (space segment)

Satellites are orbiting the earth in various altitudes across different GNSS implementations. It is typical for GNSS of global coverage to operate at low to medium orbits, where the satellites need to move at angular velocity greater than the Earth's, in order to maintain altitude. Conversely, GNSS instances of localized coverage, like BeiDou (partially), commonly utilize satellites flying at precisely the altitude where the angular velocity of movement required to preserve orbit matches exactly the Terrestrial one. Objects at orbits of that altitude have the advantage that take less effort to up-keep due to reduced atmospheric drag in comparison to lower orbits.

Since all orbits around the earth - at any altitude – are co-planar with one of the Earth's Great Circles because of gravitational forces, satellites that rotate at the altitude that allows for the same angular velocity with Earth, and in addition are in the plane of the Equator (i.e. perpendicular to the Earth's axis of rotation at all times), are always facing the same aspect of the planet and are thus called geostationary. In other words, these satellites can always be found at a constant azimuth and always at zero elevation.

Satellites of the same altitude to geostationary ones, but at a titled plane w.r.t. the Equator, tend to fly over certain locations on the Earth in a “loitering”, “figure-8” motion around a specific place on Earth. That is the case of the Japanese QZSS.

Satellites of different altitudes that are not co-planar to the Equator, have the potential to fly over any point of the globe eventually. This is the case with Galileo, GPS and GLONASS. Finally, satellites flying at different angular velocity to the Earth but above the Equator will visit every location above that particular Great Circle.

Good separation among satellites is crucial for optimal performance and acceptable accuracy. This can be an issue in non-geostationary satellites and especially those moving at angular velocities other than the Earth's, as they have to cross paths.

Regardless of altitude or geosynchronicity status, an adequate number of satellites has to be visible from any point of the intended service coverage area (localized or global). Satellites obviously serve a countless number of client devices (receivers) on Earth. It is important to remember that communication between the space segment and the client devices is one-way: Satellites broadcast their signal, without waiting for any type of response. In fact, it's impossible for them to "know" how many GNSS receivers there are. Specialized elements of the GNSS ground segment are the only exceptions that can actually relay information to the satellites.

Satellites transmit information encapsulated in packets, "frames", over specific frequencies. The message therein is threefold:

- Sat ID (known as PRN number) and an extremely precise timestamp.
  Since transmissions happen on the same frequencies across the entire GNSS implementation, satellites cannot be identified by the frequency channel alone. That is the reason identifier codes are also transmitted.
- Coarse orbital data of the entire constellation (a document known as "almanac")
- Precise orbital data of the transmitting satellite only (data tables known as "ephemerides")

Orbital data provide consensus on the position of satellites in relation to the Earth-centred, Earth-fixed coordinate system (ECEF), at exact time schedules.

Each frame carries a fragment of the above three documents, and several consecutive frames are required to download the complete dataset to a receiver. This process can take time and that is why ground equipment usually caches (recent only) orbital data. The almanac itself can also assist in accelerating this process: If a receiver downloads the almanac and already has a vague estimation of its own position (maybe a cached recent calculation), it can quickly determine the cluster of PRNs that should be visible at that moment, prioritizing the download of their ephemerides.

3.1.2. Ground control segment

The term refers to the overall support and maintenance services that include satellite tracking facilities to monitor the constellation, a control infrastructure to support decision-making and communication antennae to upload information on the satellites, including updated ephemerides. These tasks are multifaceted, highly technical and without much room for errors.

In the case of GPS, Monitor Stations scattered around the globe. They routinely:

- Track GPS satellites as they pass overhead,
- Collect navigation signals and their metadata thanks to sophisticated receivers,
- Gauge atmospheric parameters.

That information is fed into the Master Control Station, which commands and controls the entire constellation. It:

- Uses global monitor station data to compute precise location of the satellites,
- Generates navigation messages for upload to the satellites,
- Monitors satellite broadcasts and system integrity to ensure constellation health and accuracy,
- Performs satellite maintenance and anomaly resolution, including repositioning satellites to compensate for orbital decay.

Finally, Ground Antennae:

- Send commands, navigation uploads and processor program loads to the satellites.
- Collect telemetry.

3.1.3. Principle of operation

A receiver compatible with a GNSS constellation, calculates its position in space by:

- Taking the radio wave propagation speed for granted, both in vacuum and the various atmospheric layers,
- Having a reference of the exact position in time and space of each satellite of the constellation (after having downloaded / updated orbital data),
- Having parsed the identity and the exact timestamp of transmitting satellites from their signals,
- Having calculated the time difference of the timestamp of each transmitting satellite from its own on-board clock, so that it can:

  …Calculate its distance from each one of them.

What follows next is a multilateration problem, the solution of which requires at least 3 satellites. In actuality, more satellites are needed: The clock embedded into the receiver cannot achieve the superb precision of the satellite clocks due to reasons of portability and cost. The fact implies that even the tiniest of errors in the calculation of time difference would result in enormous shifts in distance measurements, given the extremely high speed of electromagnetic radio waves.

The inclusion of an extra satellite for the multilateration solution, eliminates yet another degree-of-freedom represented by that ambiguity, producing location estimations with errors of a few meters, which is deemed acceptable. Better yet, the utilization of even more satellites improves accuracy and reduces estimation uncertainty. A good receiver selects the satellites that demonstrate adequate signal-to-noise ratios and are well-spread on the sky from its position.

3.2. GNSS systems in service today

Nowadays, several GNSS constellations exist. Some were briefly mentioned in previous sections. The major ones are presented in **Table 1**, accompanied by some of their characteristics and specifications.

Table 1. Major operational GNSS constellations

System	GPS	GLONASS	Galileo	BeiDou	Quasi-Zenith
Origin	U.S.A.	Russia	European Union	China	Japan
Website	www.gps.gov	www.glonass-iac.ru	www.gsa.europa.eu	en.beidou.gov.cn	https://qzss.go.jp/en/
Type	Military use	Military use	Commercial and private use	Military and commercial use	Personal use
Encoding	CDMA	FDMA	CDMA	CDMA	CDMA
Track height	20,180 km	19,130 km	23,222 km	21,150 km	32,000 km
Accuracy	5 m	5 - 10 m	1 m 0.01 m encrypted	10 m 0.1 m encrypted	10 m
Period	11.97 hours	11.26 hours	14.08 hours	12.63 hours	23.56 hours
Satellite number	**31** (at least 24 based on the planning)	**28** (at least 24 based on the planning), including 24 in operation **2** Under control of the main supplier and 2 in a test flight phase	**4** satellites in orbit validation + 8 fully functional in orbit and 22 fully functional budgeted satellites	**5** geostatic orbit satellites **30** medium orbit satellites	**5** satellites in orbit **7** in the future
Status	Operational since **1995**	Operational since **2015**	Basic operation since **2016**. High Accuracy Full Service to be ready by **2024**	Regional operation since **2012** Under development on global scale until **2020**	Operational since **2017**

3.3. GNSS extensions

The methodology for position acquisition GNSS relies on, as described previously, is not perfect. In fact, there are problems with the principles of operation:

- A class of errors pertain to the possibly erroneous information transmitted by the satellites. It is plausible that the control segment of a GNSS system has made oversights in calculating the orbital trajectories of one or more satellites and uploaded inaccurate ephemerides to them. In turn, the satellites will broadcast the same mistaken orbital data to any listening receiver on earth. Solution for these types or errors lie almost entirely with the services tasked with the maintenance and upkeep of the constellation and are generally outside the control of the general population, independent researchers or GNSS enthusiasts.
- Depressing as this may sound, it is safe to assume that advancements on the monitoring and prediction of orbital paths of satellites will likely lead to the ever decreasing severity of such phenomena.
- Another category of errors are akin to the propagation of GNSS signals from satellites to the ground. It's worth remembering that GNSS positioning depends on accurate distance measurements of the receiver to the transmitting satellite by comparing time difference or transmission until reception and thus calculating the distance (given the standard speed of electromagnetic signals propagation in near vacuum).

This methodology has obviously served mankind well so far, but unlike Achilles, it has far more than one vulnerable heels exposed:

- <u>Loss of line-of-sight</u>

  Depending on where a GNSS receiver might be situated, a direct line-of-sight to one or more satellites of a compatible constellation might be blocked. As such, their transmissions cannot be read.

- <u>The multipath problem</u>

  In places where the receiver is surrounded by tall structures in close proximity, it is possible that the signals from one or more satellites reaches it directly as it should, in addition to other pathways, those being reflections from said structures. Those multiple paths yield slightly different travel times, hence different distances (with the reflected signal taking of course the longest). Sometimes, the ambiguation can be cleared and the reflections filtered by the more advanced of receivers. On other occasions, where the signal can only reach the receiver via reflection, the location calculated may be shifted.

- <u>Non-uniform air density throughout the layers of the atmosphere</u>

  Electromagnetic waves propagate a little slower in the atmosphere and the delay depends also on the various densities in the atmospheric layers. Higher layers like the ionosphere and the stratosphere are relatively calm in comparison to the lower ones. However, while such delays are compensated in calculations, transitive changes in air masses do occur, affecting time measurements significantly.

- <u>Non-uniform and hard to predict water vapor density in the troposphere (a.k.a. weather phenomena)</u>

Much like the unpredictability of delays due to the mutability of air masses, hence uncertainty in distance calculations, the lowest of the atmospheric layers presents the wildest variations: turbulent winds and weather phenomena like fog, rain and others. Those water particles delay signal propagation even further.

- Dilution of Precision (D.O.P.)

The ambiguity in distance measurement from each satellite can be visualized not as a sphere, which represents the entire set of points having equal distance from a given point, i.e the centre of the sphere (the satellite in our case), but as the space between two concentric spheres. The inner, smaller one, corresponds to the lower bound of the confidence interval the distance lies within, while the outer the maximum value of the same distance in that interval. A larger divergence in the radii of the two spheres means greater uncertainty in the distance estimation.

When factoring in the distance measurements from the rest of satellites, the area eligible to contain the location of the receiver is the intersection of the spaces between the two spheres of each satellite. Obviously, good accurate measurements from each satellite would close the gap between those two spheres for each sat, but DOP shows a different perspective: The angles in azimuth and elevation formed in the receiver between each sat pair combination greatly impacts the overlap in those conceivable inter-spherical spaces, thus increasing the uncertainty in the final position, regardless of the uncertainty in the distance measurement for each single emitting source. The same subset of satellites would lead a given receiver to different results if they were clustered together in the sky, versus well-spread on it, ceteris paribus (ephemerides error, atmospheric conditions, etc).

Not much can be done to compensate for poor DOP. Luckily, the control segment of a GNSS constellation tries for adequate separation between satellites, but for those constellations flying at orbits other that the geosynchronous one, the satellites are at motion relatively to the earth and to each other as well, so the aforementioned angles are constantly changing. Most receivers can calculate the DOP and its various components, like the impact it has in positioning horizontally & vertically. When more satellites are in sight, good receivers will use the subset that provides an acceptable DOP, in addition to other parameters like signal strength.

3.3.1. GNSS enhancements

To achieve more reliable and accurate distance measurements from the emitting satellites to a receiver, various techniques are employed. The list below is non exhaustive, but includes a brief explanation of majority of important advancements:

1. *Differential GNSS, a.k.a. D-GNSS, DGPS*

The technique involves the use of a network of stationary GNSS receivers, each placed in a well-determined location with very high accuracy. Every station has an operational GNSS receiver and continuously reads the calculated position from it. Subsequently, it compares the calculation to the already known, immutable (and above anything else: correct and highly precise) location of itself. The difference in all three axes (latitude, longitude, elevation) is encapsulated as an error vector and broadcast to nearby GNSS receivers. Of course, those may be mobile and incapable of ascertaining their own position extraneously, unlike the D-GNSS station.

This method assumes that whatever the reason for the error in calculation, the same reasons must hold validity in the same vicinity for other receivers, too. Indeed, the closer a compatible GNSS rover (service consumer) to the D-GNSS station (provider), the more reliable this method becomes.

2. *Real-time Kinematic, RTK*

This approach usually employs the Differential GNSS technology in addition to carrier-wave measurements. RTK kits typically contain two similar devices, one being designated as the “base“ station, i.e. a receiver meant to be stationary at least in the short run, like a session / usage. This comes in stark contrast to the completely immutable D-GNSS stations: a degree of flexibility is present with RTK set-ups. The fixed position of the base station is either input by a surveyor who determines the position exogenously, or can be approximated via lengthy sampling runs of the base station itself. The designated “rover“ receiver, i.e. the beneficiary of the enhanced precision service, receives corrections from the base station in regular intervals: The two receivers maintain communication via a dedicated RF channel and relevant equipment like antennae.

What truly sets RTK apart from D-GNSS though, is the fact that it uses the satellite signals' carrier-wave itself as a distance measuring apparatus, and not only the information contained in the packets carried by the signals. More specifically, that systems tries to figure out the wave phase (i.e. what portion of the standard wave length has elapsed since the completion of the last cycle) and the number of complete wave “cycles“ (i.e. complete wave lengths) between the satellite and the receiver. Since one packet spans over multiple wave lengths, figuring out the number of wave lengths for distance calculations can yield much more fine-grained results, with minimal vagueness in comparison to packet parsing alone and determination of clock difference.

The derivation of that wave length count is non-trivial and happens after estimation of position with the standard method of reading signal contents. Only then, RTK systems proceed to the solution of the problem known as "integer ambiguity search". While the solution to such problems is outside the scope of this paper, it is briefly worth mentioning that after achieving a distance measurement though packet parsing, i.e. reading the signals like a non-RTK device would do, a range of possible integers (that is “whole cycles“ / “wave lengths“, in this case), is given which would contain the actual count of wave lengths between emitter and receiver. As more transmissions come through, the range is narrowed down using a combination of methodologies, including the changing satellite position (changing geometry), signal-to-noise measurements and statistical approaches. Depending on the implementation, some RTK set-ups may take advantage of the twin receivers to further collect observations, share data and reach a conclusion faster. RTK offers centimetre level accuracy, commonly with an error of less than 10 cm.

3. *SBAS - Satellite-based Augmentation System*

This can be conceived as a form of Differential GNSS, the main difference being that the correction signals are broadcast by dedicated satellites. Similarly to D-GNSS, a ground based station network of pre-determined positions, each equipped with GNSS receivers, calculates the error vectors.

Instead of transmitting those correction data to client receivers directly, the information is sent to the dedicated satellites to increase correction message availability to clients. Flavours of this system, geared towards civil aviation do exist. The most well-known is FAA's WAAS (Wide Area Augmentation System) and builds upon GPS functionality. It covers Most of Canada, the continental United States and Mexico.

Europe has a solution of their own: EGNOS (European Geostationary Navigation Overlay Service). Some similar systems exist elsewhere, like QZSS-SBAS (Japan), GAGAN (India), BDSBAS (China) and

SDCM (Russia). The localized service coverage of those systems requires that correction broadcasting satellites be located constantly above the service area. As such, the sats fly at geostationary orbits, regardless of the base GNSS constellation they provide augmentation for, like Galileo or GPS.

4. *Assisted GNSS (A-GNSS a.k.a AGPS, aGPS)*

This is a set of techniques that utilize high-speed internet to speed-up, and in various ways facilitate, the computation of a position fix of broadband-capable portable telecommunication devices. It is extremely common in the embedded GNSS receivers of modern smartphones and so seamlessly integrated, that from the user's perspective, it is rather difficult to tell whether a position fix is derived by the device alone or via contribution from the network operator's A-GNSS service. Service providers have a set of base stations equipped with GNSS receivers, which collect orbital data from the supported constellations (ephemerides and almanac). The latest data are cached onto servers and when client devices request assistance over the network, aGPS works primarily in two modes:

1. Mobile Station Assisted (MSA)

   Client devices send received timestamped information (or fragments of it), to the network for processing. The service provider responds with the calculated position. This mode is associated with centralized computational costs for each client by the network service provider, and is not really necessary any longer since smart devices became quite capable in that regard lately.

2. Mobile Station Based (MSB)

   This alternative is far more common than MSA nowadays. It is used to speed-up the initial time-to-fix, by serving complete orbital data that were previously cached in the aGPS servers. Otherwise, a completely “cold“ GNSS receiver (one without stored valid orbital data) can take up to 13 minutes to fully download almanac and ephemerides in addition to the time needed for multilateration calculations. This mode can also assist in location derivation by acting as a precise time server.

5. *Ground-based multilateration*

This is a multilateration / multiagnulation technique that is technically unrelated to GNSS. It is worth a mention however, due to its prevalence in smartphones, where in tandem with aGPS, it discreetly supplements the embedded GNSS receivers' capabilities, mostly in acquiring a first position estimate quickly, though usually less accurately than standard GNSS positioning accuracy.

To achieve a location estimation, the handheld device makes use of its telecommunication antennae to figure out the direction of cell towers in reach and/or Wi-Fi access points of already known location. Subsequently, a crude estimate of its own position can be extracted. When GNSS position fixes become available, positioning is refined further.

3.4. Typical GNSS receiver specifications

GNSS receivers are electronic devices that receive and digitally process signals from GNSS satellite constellations in order to provide user's position, velocity and time. The size of GNSS receivers has been significantly minimized, allowing easy use and portability. Indicative dimensions of such devices may vary. During the past years, positioning with low-cost GNSS receivers has become very popular in many engineering and agricultural applications [7]. In most of the times, an antenna is used as a component for receiving the signals and a unit for processing the received signals. In general, prices of GNSS receivers vary between 3,000 $ and 30,000 $. However, price of a low-cost GNSS receiver starts from 200 $. The specifications of a GNSS receiver mostly rely on the number of tracking satellites, the number of channels supported, the time of signal reacquisition, the RTK correction, and further technical aspects and specifications that shape the system.

4. Precision Agriculture as a tool for optimizing farming operations

Small steps towards improving decision-making in the agricultural domain were made during the 1920s [8]. It is stated that the idea of Precision Agriculture (PA), was then born, due to the enormous needs of the agricultural. The aforementioned agricultural production derived by the need to cover nutritional needs of the constantly increasing world population. The old-school agricultural production systems were enforced to modernize in order to align with the current situation, leaving less room for non-adopters of innovative technologies.

However, it was not until the 1960s that the massive integration of decision-making and holistic approaches, were transferred to the agricultural production in reality. Mechanization of the production was a one-way road and thus, the Green Revolution introduced a package of practices for transition towards novel ways of performing agriculture [9].

This led to a wide availability of solutions about farm management aiming to support the various daily agricultural practices exercised. Application of fertilizers, synthetic pesticides and plant protection products in general, were placed on the top of the list, together with seeding and soil management, in order to reduce the chemical input in the food production chain, allowing multiple benefits for both the environment and the producers/farmers [10].

Precision Agriculture (PA), or Precision Farming as also expressed (**Figure 1**), can be defined as a management strategy that exploits Information Technology (IT) for gathering, processing and analysing spatial, temporal, and individual data, and combines it with other information to support management decisions based on variability estimations for improved use of resources (water, energy, etc.) aiming to increase productivity, efficiency, profitability, and product quality of the agricultural goods produced [11].

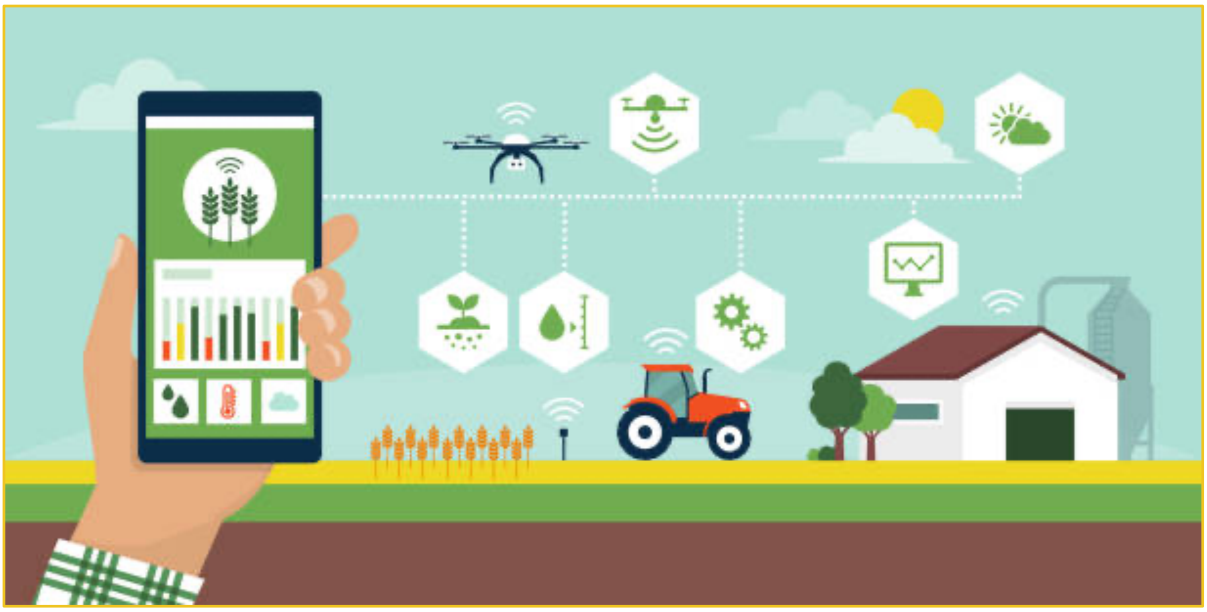

Figure 1. *Precision agriculture depiction* [12]

Nowadays, the technological progress has allowed the broad adoption of the aforementioned management strategies and technologies, while has also contributed in stimulating the awareness for the existence of such tools. As a result, during the attempt to regulate the current situation with the market and environmental demands, farmers turn to embrace the concept of Precision Agriculture.

After having tangible results on the economic benefits by the adoption of PA, farmers over the world, have been persuaded that the solution to the ongoing farming crisis lies on sustainability. In this framework, industrial corporate social responsibility (CSR) plays a significant role for assuring the proper integration of PA, by always keeping anthropocentric approach as pillar of primary production with respect to the environment [13].

The PA can be introduced in different aspects of agricultural practices, meaning that it can be incorporated for a variety of actions needed by the side of the producer during the entire production chain. The aforementioned are presented in **Figure 2**.

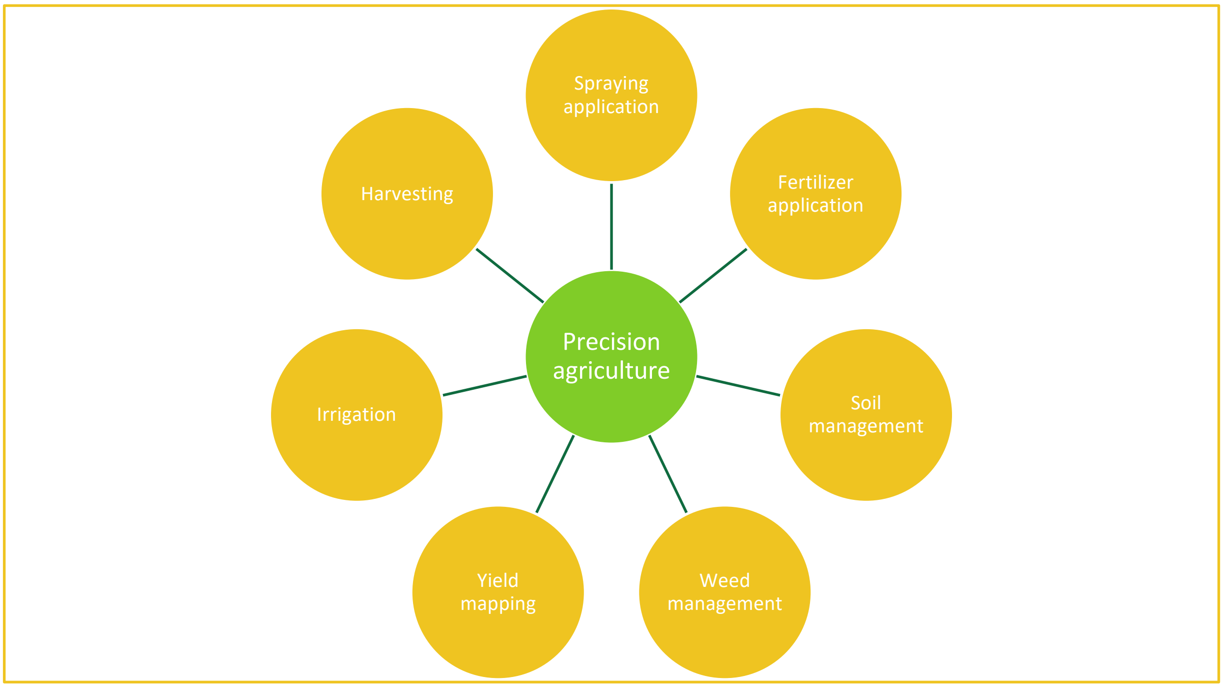

Figure 2. *Precision agriculture practices*

In all the aforementioned aspects of agricultural practices, several types of technologies have been utilized and exploited for the adoption of PA (**Figure 3**).

Multispectral imagery has been exploited for the NDVI (Normalized Difference Vegetation Index) calculation [14] and has found also various other applications [15]. On the other hand, robotics have mostly been used for fruit harvesting [16], pest and disease management applications, weed control [17], and nutrient management [18]. In addition to that, positioning systems have been used together with geospatial technologies for multiple purposes that refer to the application of fertilizers and exercising of several other good agricultural practices (GAPs) [19]. However, it is worth mentioning that the wide use of smart farming tools, has brought up security aspects. As a result, integrity, confidentiality and privacy should always be prioritized. Thus, recent research results introduce the need to establish elaborate protocols and layering for users' access to such systems, aiming to mitigate different risks deriving by the use of IoT systems [20].

Despite the aforementioned threats, adoption of PA applications, has the potential to offer numerous advantages to the farmers and the environment, related to a variety of economic aspects [21]. More precisely, regarding the farmers' cost saving from PA, two main advantages are reported. Firstly the decrease of cost, and secondarily the increase of yield that indirectly leads to increase of cost saving. Direct cost saving may derive by reduced applications of pest and plant disease management, reduced weed management applications, reduced fertilizing applications, energy and water sources conservation, strengthening of biodiversity/natural populations of beneficial organisms and micro-organisms that leads to reduction of cost input for farm management, increased profitability, reduced risk, and increase of yield through improvement of the cultivation's status and the entire unit's prosperity [22]. In addition to that, farmer benefits from the improvement if his/hers quality of life, by the reduction of the effort needed and the time consumed for farm management.

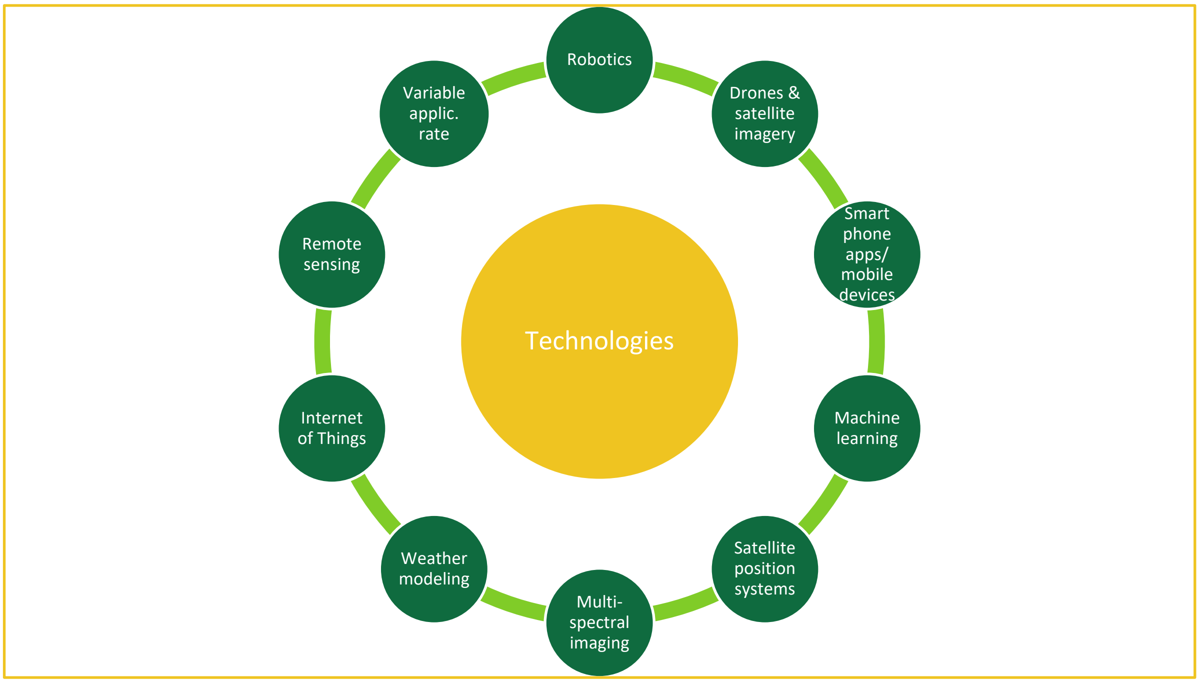

Figure 3. *Technologies exploited in precision agriculture*

As a result, during the recent years, several research results have been expressed regarding the adoption of precision agriculture globally [23]. Furthermore, strategic opportunities deriving by the exploitation of digital applications of "Agriculture 4.0" have been assessed aiming to provide an integrated methodological approach for the modernization of the agricultural sector [24]. Results indicate the wide use of innovative tools, expressing the imperative need for establishing proper training operators for allowing end-users to be assisted, advised and guided; and stimulation of awareness among farmers for allowing even wider adoption and familiarization.

4.1. Generic introduction for PA and the usage of GNSS on agricultural domain

In the context of precision agriculture, GNSS has widely been used for several agricultural applications. More precisely, GNSS sensors are amongst the most prominent sensors used in smart farming application for smartphones, with a percentage of around 40% of them using a GNSS sensor [25]. Apart from that, GNSS has been exploited for food traceability [26], for harvesting [27], for automatic steering of agricultural machinery, harvest yield mapping, soil mapping, planting, water deficiency, and variable rate application of plant protection product applications [28]. Additionally, GNSS correction signals for agricultural vehicles have also been assessed [29].

5. Modern agricultural applications analysis

During the last years, technological progress has allowed an impressive modernization of the agricultural sector. Practices that were exercised by human hands and eyes during the past, are now possible with the use of modern devices and tools. This has empowered the minimization of errors' occurrence, while has simultaneously decreased the time consumed in field, leading to higher income for the farmer together with fatigue reduction. Addressing food safety and climate change mitigation was also made possible through the integration of innovative tools and systems.

Machinery for specific agricultural practices has introduced the mechanisation of the application of agricultural practices in the framework of sustainability. Improved seed technologies have decreased the need for pesticides and/or herbicides, while seeding technologies have balanced the need to cover any possible loss of seedlings due to seeding under not optimum conditions or inappropriate soil and weather conditions.

Moreover, harvesting yield mapping (**Figure 4**) has allowed an in-depth investigation of several parameters that influence the final production yield. As the old fashioned harvesting by hand, has been replaced to a certain extent by the mechanical harvesting using novel machinery, fast harvest, with less fatigue, in less time has been allowed.

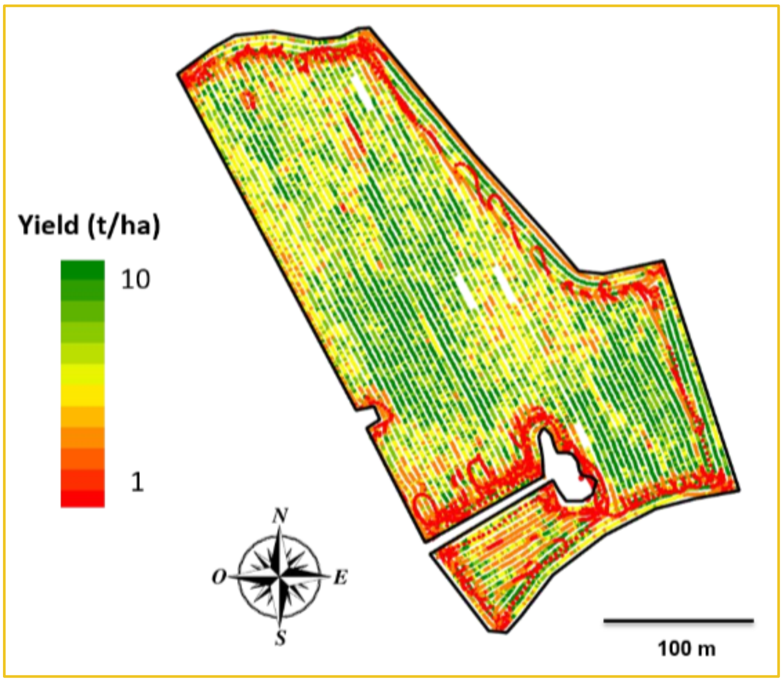

Figure 4. *Yield map depicting spatial variability of yield within a field* [30]

Initially, applications were mainly targeted to arable crops. Mechanization of harvesting was introduced by sensors that were placed on the machines to map yield variability. During the early 1990s applications were also applied in cereals using impact or γ ray grain flow sensors [31]. Later applications were developed consequently for cotton cultivation using light sensors [32], sugar beet [33] and processing tomatoes [34], hay producing crops [35], peanuts [36]. The several applications in fruits and vegetables were rather delayed and started to be widely used by the end of the 1990's and on. This delay may partially be attributed to the lack of appropriate technology [37]. The only disadvantage is the relatively low mechanization of harvest for high value crops, in respect to grain cereals and fodder legumes crop.

In general, the most common way to map the yield is by use of the Normalized Difference Vegetation Index (NDVI) which is a numerical index based on the visible and near-infrared bands of the electromagnetic spectrum that indicates if a target being observed contains live green vegetation or not (**Figure 5**). There are many applications of NDVI for either agriculture or environmental solutions.

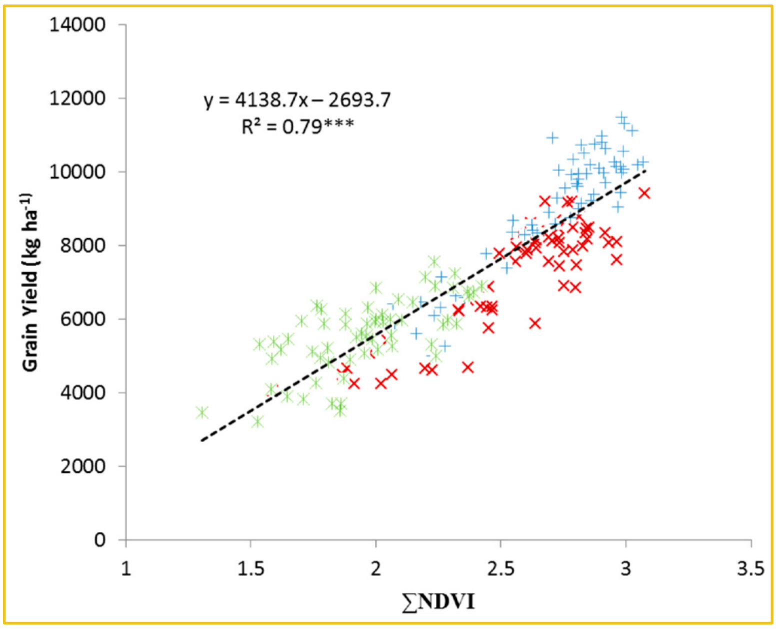

Figure 5. *Indicative correlation of NDVI and production yield* [38]

According to physics, healthy vegetation absorbs most of the visible light that falls on it, reflecting a large portion of the near-infrared light. On the other hand, unhealthy or sparse vegetation reflects more visible light and less near-infrared light (**Figure 6**). As for bare soils, they reflect moderately in both the red and infrared portion of the electromagnetic spectrum [39].

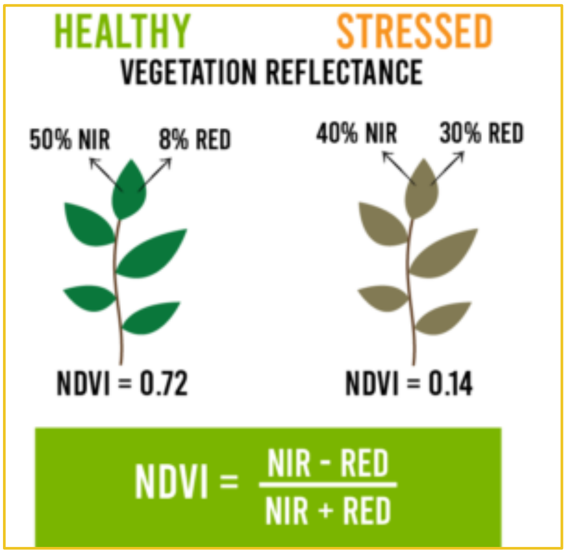

Figure 6. *NDVI for healthy and stressed plant* [40]

The visualization of NDVI index can be performed by producing custom maps that allow easy understand of the data retrieved (**Figure 7**).

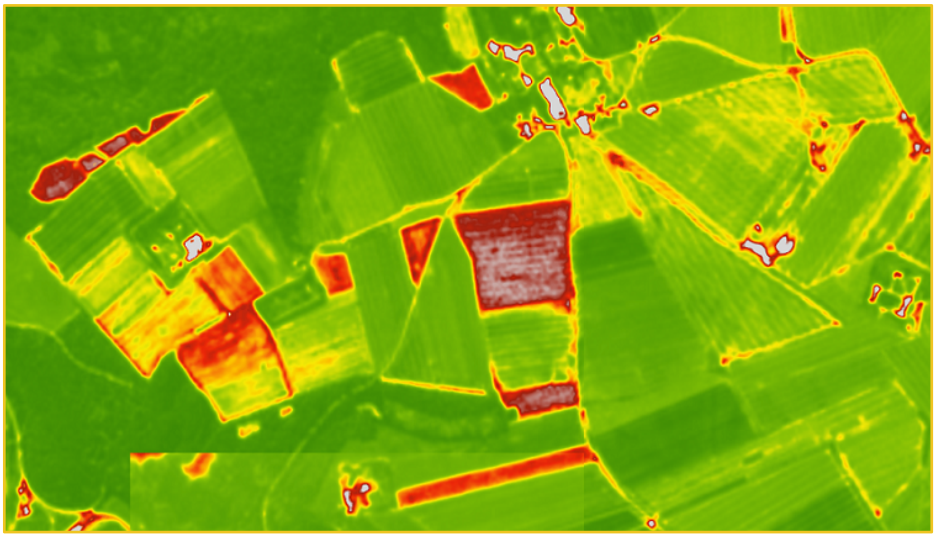

Figure 7. Visualization of NDVI index [41]

Furthermore, elevation maps (**Figure 8**) have allowed an in-depth understanding of the effect of soil formation, and water capacity in distinct cropping aspects. Elevation maps can be used in modern agriculture for the optimization of planting, seeding and ploughing agricultural practices.

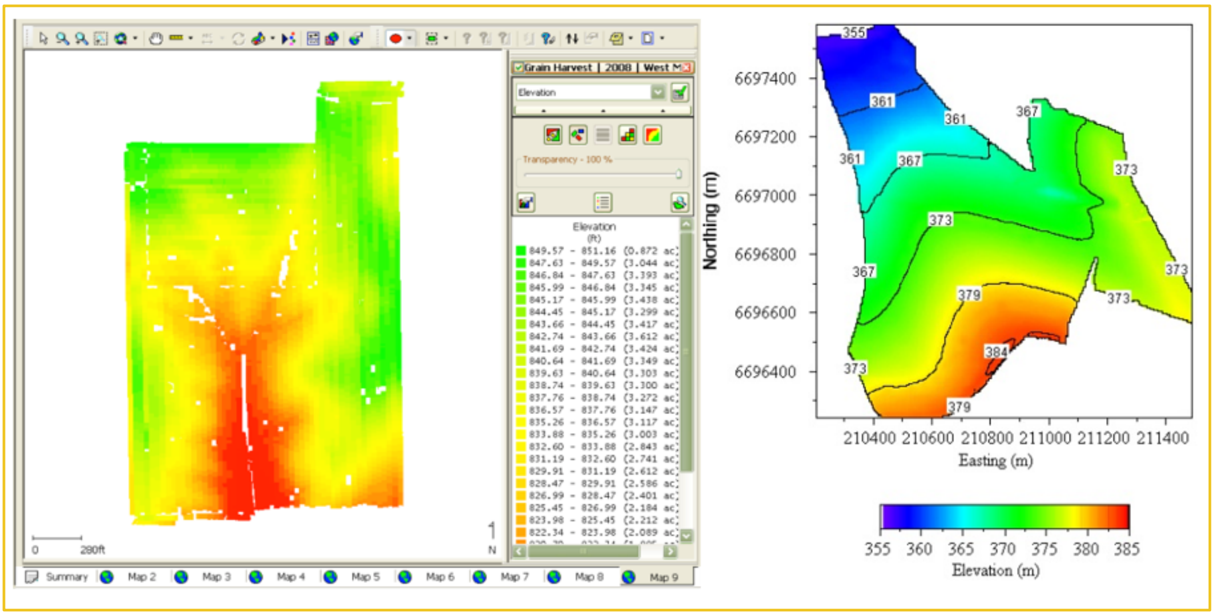

Figure 8. Example of elevation map

As elevation data may be collected by any GNSS receiver, the RTK systems can significantly assist in increasing the accuracy of soil analysis. Sensors can also be used as a fast and low cost method for assessing soil parameters. Such sensors may be based on electrical and electromagnetic (EM), optical and radiometric, mechanical, acoustic, pneumatic, and electrochemical measurements. Using the data from the GNSS receivers, it is possible to produce a Digital Elevation Model (DEM) of a field or a farm. This DEM can be used to identify specific terrain attributes, such as slope, aspect, curvature, solar radiation interception, landscape water flow directions and topographic wetness indices.

Furthermore, variable rate application has allowed minimizing the chemical input in the food production chain, reducing any possible risks imposed to human health and the environment by the irrational and unsustainable use of plant protection products (PPPs). Two methods are used to apply variable rate application. The first one called map based, is based on historical data (previous or present year). Process control technologies allow information drawn from the GIS (prescription maps) to control processes such as fertilizer application, seeding rates, and herbicide selection and application rate, thus providing the proper management of inputs. The second, named sensor based, uses sensors that can adjust the applications rates on the go. The sensors detect some characteristics of the crop or soil and adjust the application equipment. VRA can be applied to all inputs like fertilizer application, spraying for pests, water application but also for practices like pruning. As a result, variable rate application (**Figure 9**) has empowered achieving optimum result of PPPs' application, leading simultaneously to efficient pest and disease management, fertilizer application, weed management etc. Regarding weed detection, two main ways have been introduced. More specifically, one way is to detect the seed placement in the field using a RTK-GPS and then produce maps with the plant places. The second is to use a camera in front of the machine to detect weeds and crop plants and direct a tool only to the weeds.

Figure 9. *Variable rate application technology* [42]

In addition to that, latest progress in development of novel tools for the application of plant protection products and field scouting has led to on-time management of pests and diseases, reducing any losses due to disease outbreaks. In this context, modelling of pests and diseases, together with crop modelling has significantly contributed in ensuring the production. In this holistic approach, Decision Support Systems have been developed and exploited towards this direction together with farm management information systems (FMIS). The aforementioned DSSs facilitate decision-making, after exploitation of appropriate models and databases, by providing useful advices to farmers (**Figure 10**).

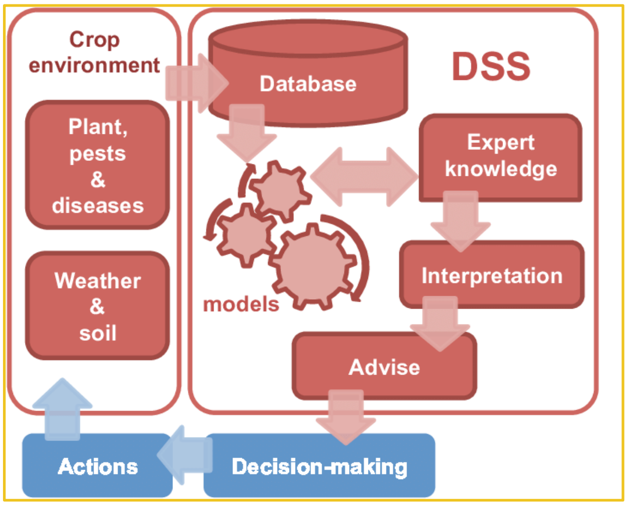

Figure 10. *Schematic representation of a DSS* [43]

Another very significant modern agricultural application that has been introduced is smart irrigation (**Figure 11**). During an era of water deficit, the need of sustainable use of water has been addressed by the introduction of automated deficit irrigation for covering the plants' needs, while also minimize the overspending of natural resources such as water. As over irrigating does not only lead to water resources' spending, leads also to the development of favourable conditions for growth of various fungal plant pathogens that may cause severe diseases and consequently lead to the need for further plant protection product applications.

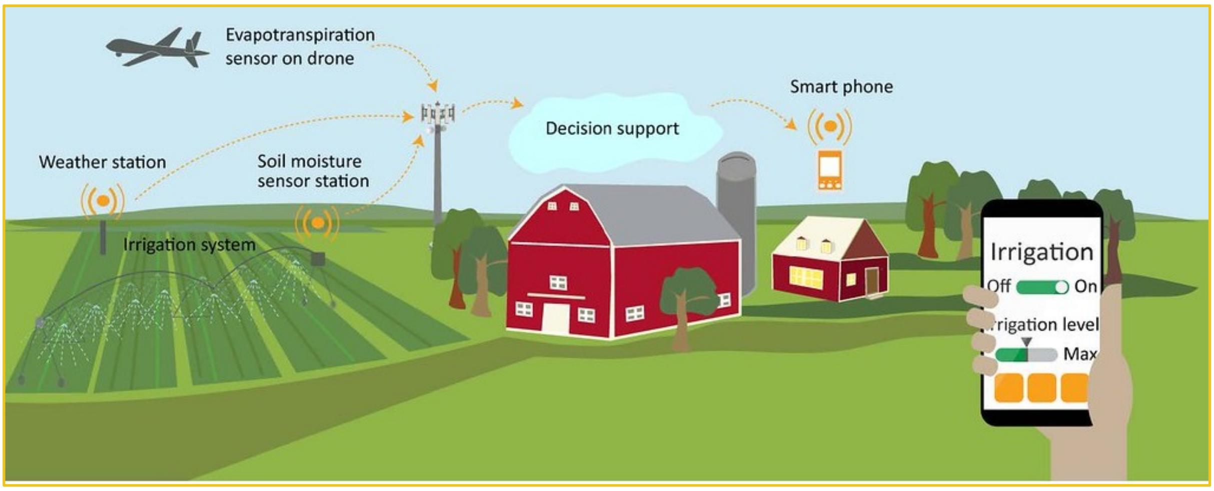

Figure 11. *Smart irrigation schematic representation* [44]

Additionally, unmanned aerial vehicles (UAV), widely known as drones, have been used in modern agriculture for several purposes. The flight of UAVs may be controlled either autonomously by on-board computers or by the remote control of a pilot on the ground or in another vehicle. In this way, performing a flight above a field, allows access to very useful information for agricultural practices applications (**Figure 12**).

Figure 12. *UAV flying above a field*

There are two main platforms for UAVs, more precisely, a fixed wing and a multi-rotor. A fixed wing platform has the advantage of covering large areas efficiently, whereas a multirotor is able to remain very stable in challenging conditions with large payloads. UAVs are equipped with a GNSS receiver that is used primarily for location information for the autopilot and of course for the data collected to be linked to its spatial position. In addition, UAVs have autopilots in order to be programmed to fly over a certain area and collect the desired data. In many cases, UAVs communicate with a ground control station (GCS) via radio link. GCS is usually just a laptop computer with software for planning route. The same software is also used to set the flight paths for the UAV missions. Existing GNSS receivers are compact and provide 1m and 2m vertical and horizontal respectively. These receivers including an IMU (Inertial Measurement Unit) for detecting changes in pitch, roll, and yaw and for enabling dead reckoning capabilities. These systems are affordable and are adequately accurate for most practices.

UAVs already offer new alternatives for agriculture and other applications in which high spatial resolution imagery delivered in near-real time is needed. Diagnostic information derived from images collected from on-board sensors, such as biomass, LAI, disease and water stress can thus inform decision-making in crop management, yield forecasting and environmental protection [45]. When imaging sensors are used with UAVs, it is required to take overlapping images in order to achieve full coverage of the field under investigation.

Furthermore, driver assistance and auto-steering features are introduced in modern precision agriculture. Autoguidance systems are offered as two options, the lightbar and the auto-steer. Both systems use a high accuracy GNSS receiver (Horizontal < 1 cm, Vertical < 2cm to identify the tractor's location in the field [46].

The basic difference between the two systems is that a LightBar requires the operator to manually adjust steering, while auto-steer technology adjusts the steering automatically, allowing the operator to monitor the field operation of the implement instead of wheel steering. LightBar technology is offered at a much lower cost and can be easily transferred from one vehicle to another in comparison to auto-steer technology, which requires higher investment capital and it can differ from one machinery manufacturer to another.

Guidance systems are regarded as the most adopted PA technologies worldwide and can be used for many field operations such as seeding, tillage, planting, weeding and harvesting, as well as for use with autonomous vehicles (UGV – Unmanned Ground Vehicles) with the full utilization of the ISOBUS standard ISO 11783. Auto-steer reduces the overlap of multiple passes with the tractor, which is mainly caused by operator error or fatigue. The ability to increase speeds during headland turns and more quickly identify re-entry points were recorded to reduce machinery time requirements by 5 % for planting and 10 % for fertilizer application [47].

Additionally, Light bar driver assistance and auto-steer is used in Controlled Traffic Farming (CTF). CTF is a system which confines all machinery loads to the least possible area of permanent traffic lanes. Current farming systems allow machines to run at random over the land, compacting around 75% of the area within one season and at least the whole area by the second season. A proper CTF system on the other hand can reduce tracking to just 15% and this is always in the same place. The permanent traffic lanes are normally parallel to each other and this is the most efficient way of achieving CTF, but the definition does not preclude tracking at an angle. The permanent traffic lanes may be cropped or non-cropped depending on a wide range of variables and local constraints. Techniques like CTF have the capacity to benefit all types of crop farming. CTF also allows optimised driving patterns, more efficient operations (i.e. reduced overlaps). As all operations are aligned, input applications can be targeted very precisely relatively to the crop rows.

Controlled Traffic Farming (CTF) management can play a key role in sustaining soils and future crop production, which are today threatened by heavy machinery traffic and intensive production systems.

To play this role in sustainable intensification, CTF needs to be developed to be allowed to become a mainstream technology rather than continuing as a niche practice. Therefore, it is required to facilitate and support the development and mainstreaming of CTF (**Figure 13**) at a time where development in allied technologies such as headland management systems are increasing growers openness to the adoption of these systems.

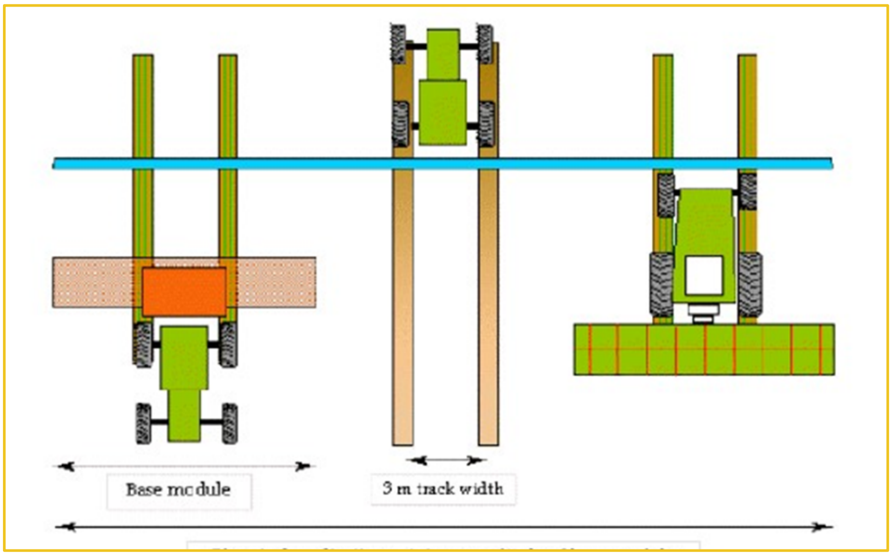

Figure 13. *CTF schematic representation*

Based on the aforementioned information it is apparent that modern agricultural practices have been widely facilitated by the technological progress observed during the last decades. In this context, GNNS technologies play a significant role in shaping future agriculture. A summary of the field operations, where GNSS technologies can be applied, is presented below.

5.1. A Summary of the field operations where GNSS technologies can be applied

Assisted by the use of GNSS and further technological innovations, new modern agricultural practices have been established, as mentioned before. As a result, practices that were not exercised during the past, are now possible for the optimization of the production in the various parts of the production chain with the use of GNSS technology. Monitoring techniques have significantly been assisted by the use of GNSS solutions. Exact in site spatial detection of pest and diseases have allowed the on-time application of plant protection production for avoiding the potential risk of disease and/or infestation outbreaks that could cause qualitative and quantitative degradation of the agricultural goods produced.

In addition to that, GNSS technologies find application in yield mapping, widely known as yield monitoring, through the analysis of several variables that affect yield, by the use of sensors, GNSS antennas, GNSS receivers, and travel speed sensors for providing harvesting time sensing. In this way, yield calculated at each field location can be displayed on a map using a Geographic Information System (GIS) software package.

Drones, that are considered to be one the greatest inventions of modern times, contribute to several agricultural application, such as seeding, crop monitoring, pest and disease monitoring, plant protection product applications (in countries where this type of use is registered), weather conditions' investigation, land fertility evaluation etc. [48]. This type of applications has strongly been supported by the wide use of hyperspectral and multispectral cameras, that can be mounted on unmanned aerial vehicles and provide a recording of the target (plant/area etc.).

Furthermore, progress observed in robotics has allowed their implementation and integration in precision agriculture. More precisely, robots have nowadays been used in fruit harvesting, vegetable picking, weeding, plant management, and spraying [49] [50]. However, without the introduction of machine learning, robotics would not be able standalone by itself to provide optimum use results in agriculture.

Additionally, GNSS technologies play a very important role in the use of sensors for remote sensing in agriculture. More specifically, in remote sensing of soil and ground characteristics and parameters, along with environmental/meteorological parameters [51]. Soil mapping is believed to be a crucial operation as it provides valuable information about soil texture (sand, silt, clay), availability of nutrients for crops to grow (P, K, Ca, Mg, pH, lime) and other soil chemical compounds (organic matter, salinity, nitrate, sulphate, heavy metals). Cloud computing, wireless sensors, and big data analytics have empowered the introduction of automation in agricultural systems.

Moreover, GNSS has empowered exploitation of auto-guidance and auto-steering in agriculture. This way, machinery can automatically be moved in the field for various agronomic practices. Such examples are the tractors' navigation [52] [53], and boundary line extraction in fields [54]. Auto-guidance systems have gained increasing interest among farmers as they enable farm machinery to follow straight lines to reduce overlaps of the tractor and equipment passes. These systems help farmers to reduce fuel costs, input costs, time, labour, soil compaction and increases the overall field efficiency.

For the purposes of AgriBIT project, several uses of GNSS in agriculture have been identified and incorporated in developed use cases. The aforementioned use cases are described in detail in **Use case scenarios analysis** chapter of the current document.

5.2. Connectivity and compatibility of a GNSS system in Precision Agriculture

Several connectivity and compatibility issues should be taken into account for developing a GNSS system for Precision Agriculture. More specifically, those are presented below:

1) ISOBUS (ISO 11783)

The technological innovations of on-board tractor performance monitoring systems and the recently advances in tractor's technology enables the acquisition of tractor and implement status and data through the ISOBUS [55], and provide useful information to optimize the overall field productivity [56]. The ISOBUS specifies a serial data network for control and communications on forestry or agricultural tractors and mounted, semi-mounted, towed or self-propelled implements. Its purpose is to standardize the method and format of transfer of data between sensors, actuators, control elements, and information-storage and -display units, whether mounted on, or part of, the tractor or implement. Combined with GPS, the system could be used for spatial mapping of tractor-implement field performances [57] [58]. Such technologies emerge as standard features on contemporary tractors and will provide enhanced farm and operations management through the use of extensive databases as the basis for decision support and control actions. Moreover, the development of autonomous vehicles adopted to various field tasks, will gradually downgrade the role of the tractor operator and will require an explicit management information system capable of managing interactive information flows and provide useful guidelines in real-time for operations execution. The interconnection between the ISOBUS and precision agriculture innovations will meet the farm manager's demands by open up a wealth of information for better management of crop production.

2) NMEA 0183

NMEA 0183 is a combined electrical and data specification for communication between marine electronic devices such as echo sounder, sonars, anemometer, gyrocompass, autopilot, GPS receivers and many other types of instruments. It has been defined by, and is controlled by, the U.S.-based National Marine Electronics Association.

Most of the PA sensors (e.g. NDVI ground sensors, on-the-go soil mapping sensors supports, etc.) are using NMEA data specification to support connectivity with GNSS receivers. This is achieved using RS-232 serial port placed on PA sensors that is used for data transferring in real time. The transfer of NMEA 0183 strings giving them the ability to log their data combined with the positioning data coming from the GNSS receiver.

3) GIS Vector output formats

Data recorded from GNSS receivers can be used for various applications in agriculture as mapping, tracking, monitoring etc. For being able for the users to analyse their data, to create maps and to monitor the agricultural operations in external tools, applications and services, the system must proving exporting capabilities to the main GIS vector output formats. GIS vector format is proving three different types of geometry (points, lines, polygons) and the main output format commonly used are:

a) KML

Keyhole Markup Language (KML) is an XML notation for expressing geographic annotation and visualization within Internet-based, two-dimensional maps and three-dimensional Earth browsers. KML was developed for use with Google Earth, which was originally named Keyhole Earth Viewer. It was created by Keyhole, Inc, which was acquired by Google in 2004. KML became an international standard of the Open Geospatial Consortium in 2008. Google Earth was the first program able to view and graphically edit KML files. Other projects such as Marble have also started to develop KML support.

b) GeoJSON

GeoJSON is an open standard format designed for representing simple geographical features, along with their non-spatial attributes, based on JavaScript Object Notation. The GeoJSON format differs from other GIS standards in that it was written and is maintained not by a formal standards organization, but by an Internet working group of developers.

c) Shapefile format (SHP)

The shapefile format is a popular geospatial vector data format for geographic information system (GIS) software. It is developed and regulated by Esri as a (mostly) open specification for data interoperability among Esri and other GIS software products. The shapefile format can spatially describe vector features: points, lines, and polygons, representing, for example, water wells, rivers, and lakes. Each item usually has attributes that describe it, such as name or temperature.

5.3. Specification requirements

For meeting the needs of the users and for being able to work in harsh environments as the agricultural one, the GNSS system must also meet the following specification requirements:

1) Dead reckoning

The system must be able to work even in “GPS-unfriendly” environments like orchard fields due to high tree canopy. Dead-reckoning is used together with GPS sensors and is able to keep high accuracy positioning by using information from various sensors (e.g. accelerometers, gyro sensors, IMU’s) for calculating the current position, even when GPS positioning is difficult [59]. Moreover, dead reckoning capabilities combined with a LiDAR can being used for UGV’s navigation with the usage of Kalman filtering. Kalman filter is a set of mathematical equations that provides an efficient computational (recursive) solution of the least-squares method. The filter is supports estimations of past, present, and even future states, and it can do so even when the precise nature of the modeled system is unknown [60].

2) Ingress Protection (IP)

The Ingress Protection rating system is a classification system showing the degrees of protection from solid objects and liquids. The first number refers to the protection against solid objects, normally dust. If the first number is 0, there is no protection provided. A number 5 refers to limited protection against dust. The number 6 is for total protection against dust. The second number of the IP rating system refers to protection against liquids. A 0 indicates no protection, while a 7 refers to protection against immersion between 15 centimeters and 1 meter. For being able to work in the agricultural environment the system must be rated as IP67 in order to be able to work in dust and under raining conditions.

3) High accuracy

In addition, there are state of the art technologies and applications in the field of agriculture that require very high accuracy (< 1cm) [46] and precision. Such technologies utilize automated non-destructive methods made for agricultural practices. Main examples of applications in agriculture sector that require very high accuracy and precision in navigation and positioning includes the guidance of large agricultural vehicles and Variable Rate Application machineries for high value crops. Other examples include autonomous mobile robotic units (UAV/UGV) for navigating into the farm harsh environment.

4) Data transferring in high frequency (up to 20Hz)

Another important factor especially in case of VRA machineries, UGV's navigation and auto steering it's the ability of the GNSS receiver to transfer the positioning data to the corresponding PA technology in a high frequency. High frequency rates (over 10Hz) helps on avoiding the application or the navigational errors that can occur through the slow rate of refreshing the positioning information which can lead to unexpected events.

6. Use case scenarios analysis

A use case can be described as a set of interdependent interactions among various systems and their components in addition to human agents in a plethora of roles. Such actions are – typically – initiated by a user of a system against the latter, towards the completion of a goal intended by that user. The interactions themselves appear atomic at the level of granularity dictated by the given scope of analysis, but may in fact consist of more discrete steps.

The following tables summarize the use cases identified for AgriBIT. Those usage scenarios have been the main tool in working together with user groups to understand their needs and requirements. Moreover, they shall subsequently assist us in completely defining the overall system specifications and attributes.

The GNSS receiver to be produced by the Consortium is being designed to conform to the use cases below.

Table 2. *Use case 1 description*

Field	Description
Use Case ID	**UC1**
Use Case Name	Mapping of stationary field elements
Short Description	This use case allows the user to digitize geo-spatial information that is preserved immutable in an agricultural field, like its boundaries, the positions of trees, the entry and exit points of agricultural machinery etc. The digitization of data via the Android application is essential and globally helpful to the rest of the use-cases in this project.

Table 3. *Use case 2 description*

Field	Description
Use Case ID	**UC2**
Use Case Name	Mapping of mobile field elements
Short Description	This use case allows the user to digitize geo-spatial information that is mobile or mutable in an agricultural field, over time. This includes data that coming both from sensors and agricultural machineries actuators.

Table 4. *Use case 3 description*

Field	Description
Use Case ID	**UC3**
Use Case Name	Route planning for unmanned vehicles and agricultural machineries
Short Description	This use case allows the user to create the optimal route for the navigation of unmanned and manned agricultural machineries / vehicles. Especially for unmanned vehicles, the kinematic characteristics (e.g. flight altitude) of the vehicle are inserted from the user and used for the route calculation.

Table 5. *Use case 4 description*

Field	Description
Use Case ID	**UC4**
Use Case Name	Navigation of agricultural machineries in arable crops (LightBar application)
Short Description	The operator of an agricultural machine will be able to use an android application for precisely following the route plan created from AgriBIT services. This application would be able to be used in any machinery not equipped with a LightBar system.

Table 6. *Use case 5 description*

Field	Description
Use Case ID	**UC5**
Use Case Name	EO based PA Services for Farmer's Decision Support
Short Description	End users maintain access to high precision services which support them in taking the right decisions for most of the major agricultural operations (tillage, irrigation, spraying, harvesting). The higher precision level in terms of land area increases the accuracy of the processed EO data.

Table 7. *Use case 6 description*

Field	Description
Use Case ID	**UC6**
Use Case Name	Graphical representation of heterogeneous data for improved decision-making
Short Description	The end user will be enabled, via a web application, to simultaneously assess all the heterogeneous information gathered from the system, perform comparisons and discern correlations that will assist him/her in the decision-making process. This use case encompasses the visualization of satellite, environmental and various other geo-spatial data along with the capability to evaluate them in a fine-grained, multi-layered scope (e.g. contrast of samples across locations within fields or comparison of sampling taken from the exact same place, over time).

Table 8. *Use case 7 description*

Field	Description
Use Case ID	**UC7**
Use Case Name	Production of advisory and intelligent early warnings
Short Description	The system's end user will be eligible for delivery of advice related to the optimal management of their cultivation. Furthermore, they shall be timely warned about threats jeopardizing their plants (e.g. leveraging disease/pest prediction models).

Table 9. *Use case 8 description*

Field	Description
Use Case ID	**UC8**
Use Case Name	Prescription mapping – Variable Rate Application (VRA)
Short Description	Variable Rate Application (VRA) technology is the major target for PA. Variable Rate (VR) means that the appropriate rates of inputs will be applied leading either to reduced inputs, costs and environmental effects or improved yields and quality. To apply VR, prescription maps will be generated for control processes such as fertiliser application, seeding rates, and herbicide selection and application rate, thus providing for the proper management of the inputs. The prescription map service will retrieve the fused and analysed data coming from the EO based PA Services and will create the maps with the information of the amount of the input that must be applied per unit of area.

7. State of the Art in GNSS with respect to AgriBIT

The analysis of commercial products and funded research activities related to the scope and possible needs of the AgriBIT project has been analysed and reported in this and follow-up sections.

7.1. Analysis of European funded research activities

The analysis of recent scientific advancements on GNSS solutions for accuracy, portability and/or energy-efficiency has been performed with respect to research activities funded earlier by GSA/EUSPA as well as from other European funding programs. The results are in tables Table 10 to Table 12.

Table 10. *List of funded research projects relevant to AgriBIT*

No	Project	Type	Homepage	Factsheet	Year(s)	Ongoing?	Call
1	SCORPION	IA	Link	Link	1/21 - 12/23	Yes	H2020-SPACE-EGNSS-2020
2	GALIRUMI	IA	Link	Link	12/19 - 11/22	Yes	H2020 - Galileo 4th Call
3	GREENPATROL	IA	Link	Link	11/17 - 9/20	-	H2020 – Galileo 3rd Call
4	RECAP	IA	Link	Link	5/16 - 10/18	-	H2020-INSO-2015-CNECT
5	AUDITOR	IA	Link	Link	1/16 - 6/18	-	H2020 – Galileo 2nd Call
6	MISTRALE	IA	Link	Link	1/15 - 6/18	-	H2020 – Galileo 1st Call
7	GEOPAL	CP	Link	Link	4/12 - 10/14	-	FP7-GALILEO-2011-GSA-1-a
8	UNIFARM	CSA	Link	Link	1/12 - 4/14	-	FP7-GALILEO-2011-GSA-1-a
9	FieldCopter	CP	Link	Link	1/12 - 3/14	-	FP7-GALILEO-2011-GSA-1-b
10	FIELDFACT	CP	Link	Link	8/06 - 8/12	-	FP6 2nd Call
11	BroadGNSS	PCP	Link	Link	1/12/20 - 31/3/24	Yes	H2020-SPACE-EGNSS-2020
12	GAMMS	IA	Link	Link	1/7/21 - 31/12/23	Yes	H2020-SPACE-EGNSS-2020
13	RADIUS	IA	Link	Link	1/21 - 12/23	Yes	H2020-SPACE-EGNSS-2020
-	~~RAILGAP~~	~~IA~~	~~Link~~	~~Link~~	~~1/21 - 12/23~~	~~Yes~~	~~H2020-SPACE-EGNSS-2020~~
14	PASSport	IA	Link	Link	12/20 - 11/23	Yes	H2020-SPACE-EGNSS-2020
15	ESRIUM	IA	Link	Link	12/20-11/23	Yes	H2020-SPACE-EGNSS-2020
-	~~GAMBAS~~	~~IA~~	~~Link~~	~~Link~~	~~1/21 - 6/23~~	~~Yes~~	~~H2020-SPACE-EGNSS-2020~~
-	~~MOLIERE~~	~~IA~~	~~Link~~	~~Link~~	~~12/20 - 11/22~~	~~Yes~~	~~H2020-SPACE-EGNSS-2020~~
16	GISCAD-OV	IA	Link	Link	12/19 - 11/22	Yes	H2020 - Galileo 4th Call
17	DELOREAN	IA	Link	Link	12/19 - 5/22	Yes	H2020 - Galileo 4th Call
18	ROOT	IA	Link	Link	11/20 - 4/22	Yes	H2020-SPACE-EGNSS-2020
-	~~PREPARE Ships~~	~~IA~~	~~Link~~	~~Link~~	~~12/19 - 1/22~~	~~Yes~~	~~H2020 - Galileo 4th Call~~
19	HELMET	IA	Link	Link	1/20 - 1/22	Yes	H2020 - Galileo 4th Call
-	~~AMPERE~~	~~IA~~	~~Link~~	~~Link~~	~~2/20 - 1/22~~	~~Yes~~	~~H2020 - Galileo 4th Call~~
-	GRIMASSE	IA	Link	Link	11/17 - 12/21	Yes	H2020 – Galileo 3rd Call
20	GAUSS	IA	Link	Link	3/18 - 12/21	Yes	H2020 - Galileo 4th Call
21	GEONAV IoT	IA	Link	Link	12/19 - 11/21	Yes	H2020 - Galileo 4th Call
22	CLUG	IA	Link	Link	12/19 - 11/21	Yes	H2020 - Galileo 4th Call
23	HUUVER	IA	Link	Link	12/19 - 10/21	-	H2020 - Galileo 4th Call
24	SIA	IA	Link	Link	3/18 - 8/21	-	H2020 – Galileo 3rd Call
25	H2H	IA	Link	Link	11/17 - 5/21	-	H2020 – Galileo 3rd Call
26	SINSIN	IA	Link	Link	11/17 - 4/21	-	H2020 – Galileo 3rd Call
27	GIMS	IA	Link	Link	11/17 - 1/21	-	H2020 – Galileo 3rd Call
28	TransSec	IA	Link	Link	2/18 - 1/21	-	H2020 – Galileo 3rd Call

29	AIOSAT	IA	Link	Link	12/17 - 12/20	-	H2020 – Galileo 3rd Call
30	HELIOS	IA	Link	Link	3/16 - 12/20	-	H2020 – Galileo 2nd Call
31	GALILEO 4 Mobility	IA	Link	Link	11/17 - 6/20	-	H2020 – Galileo 3rd Call
32	ENSPACE	IA	Link	Link	11/17 - 5/20	-	H2020 – Galileo 3rd Call
33	FLAMINGO	IA	Link	Link	11/17 - 5/20	-	H2020 – Galileo 3rd Call
34	GOEASY	IA	Link	Link	12/17 - 5/20	-	H2020 – Galileo 3rd Call
35	SARA	IA	Link	Link	2/18 - 1/20	-	H2020 – Galileo 3rd Call
36	ERSAT GGC	IA	Link	Link	12/17 - 11/19	-	H2020 – Galileo 3rd Call
37	PRoPART	IA	Link	Link	12/17 - 11/19	-	H2020 – Galileo 3rd Call
38	LOGIMATIC	IA	Link	Link	3/16 - 8/19	-	H2020 – Galileo 2nd Call
39	SKYOPENER	IA	Link	Link	5/16 - 6/19	-	H2020 – Galileo 2nd Call
40	STRIKE3	IA	Link	Link	2/16 - 1/19	-	H2020 – Galileo 2nd Call
41	STARS	IA	Link	Link	2/16 - 11/18	-	H2020 – Galileo 2nd Call
42	FOSTER ITS	IA	Link	Link	1/15 - 7/18	-	H2020 – Galileo 1st Call
43	BLUEGNSS	IA	Link	Link	1/16 - 6/18	-	H2020 – Galileo 2nd Call
44	INLANE	IA	Link	Link	1/16 - 6/18	-	H2020 – Galileo 2nd Call
45	GRICAS	IA	Link	Link	1/16 - 4/18	-	H2020 – Galileo 2nd Call
46	MOBNET	IA	Link	Link	1/16 - 2/18	-	H2020 – Galileo 2nd Call
47	5 Lives	IA	Link	Link	9/15 - 2/18	-	H2020 – Galileo 1st Call
48	SAT406M	IA	Link	Link	2/15 - 1/18	-	H2020 – Galileo 1st Call
49	EASY Pv	IA	Link	Link	2/16 - 1/18	-	H2020 – Galileo 2nd Call
50	LARA	IA	Link	Link	2/15 - 12/17	-	H2020 – Galileo 1st Call
51	spyGLASS	IA	Link	Link	1/15 - 12/17	-	H2020 – Galileo 1st Call
52	InDrive	IA	Link	Link	1/16 - 12/17	-	H2020 – Galileo 2nd Call
53	RHINOS	IA	Link	Link	1/16 - 10/17	-	H2020 – Galileo 2nd Call
54	CaBilAvi	CSA	Link	Link	1/15 - 9/17	-	H2020 – Galileo 1st Call
55	PARADISE	IA	Link	Link	1/15 - 7/17	-	H2020 – Galileo 1st Call
56	e-Airport	IA	Link	Link	1/15 - 6/17	-	H2020 – Galileo 1st Call
57	BEYOND	CSA	Link	Link	3/15 - 6/17	-	H2020 – Galileo 1st Call
58	COREGAL	IA	Link	Link	1/15 - 5/17	-	H2020 – Galileo 1st Call
59	ERSAT EAV	IA	Link	Link	2/15 - 4/17	-	H2020 – Galileo 1st Call
60	mapKITE	IA	Link	Link	3/15 - 4/17	-	H2020 – Galileo 1st Call
61	G-MOTIT	IA	Link	Link	1/15 - 3/17	-	H2020 – Galileo 1st Call
62	GALENA	IA	Link	Link	1/15 - 3/17	-	H2020 – Galileo 1st Call
63	GEO VISION	IA	Link	Link	1/15 - 12/16	-	H2020 – Galileo 1st Call
64	GHOST	IA	Link	Link	1/15 - 12/16	-	H2020 – Galileo 1st Call
65	JUPITER	IA	Link	Link	1/15 - 12/16	-	H2020 – Galileo 1st Call
66	DEMETRA	IA	Link	Link	1/15 - 12/16	-	H2020 – Galileo 1st Call
67	GMCA	IA	Link	Link	2/15 - 9/16	-	H2020 – Galileo 1st Call
68	UKRAINE	IA	Link	Link	1/15 - 9/16	-	H2020 – Galileo 1st Call
69	ELAASTIC	IA	Link	Link	1/15 - 6/16	-	H2020 – Galileo 1st Call
70	SUNRISE	CSA	Link	Link	1/12 - 1/15	-	FP7-GALILEO-2011-GSA-1-a
71	MEDUSE	CSA	Link	Link	2/12 - 9/13	-	FP7-GALILEO-2011-GSA-1-b
72	PANTHEON	RIA	Link	Link	1/11/17 - 31/10/21	Yes	H2020-SFS-2017-1
73	BACCHUS	RIA	Link	Link	1/1/20 - 30/9/23	Yes	H2020-ICT-2019-2
74	IOF2020	IA	Link	Link	1/1/17 - 31/3/21	-	IoT-01-2016 - Large Scale Pilots
75	NAVISAS	RIA	Link	Link	1/3/16 - 28/2/18	-	H2020-SESAR-2015-1
76	ROMI	RIA	Link	Link	1/11/17 - 30/4/22	Yes	H2020-SFS-2017-1
~~77~~	~~VITIGEOSS~~	~~IA~~	~~Link~~	~~Link~~	~~1/9/20 - 29/2/24~~	~~Yes~~	~~H2020-SC5-16-2019~~
~~78~~	~~ENVISION~~	~~IA~~	~~Link~~	~~Link~~	~~1/9/20 - 31/8/23~~	~~Yes~~	~~H2020-SC5-16-2019~~

Table 11. *Domains of identified funded research projects relevant to AgriBIT*

No	Project	Domain/Market (as classified by EUSPA)										
		Agriculture	Aviation	Maritime	Railways	Road	Surveying/Mapping	Timing/Synchronisation	Search and Rescue (SAR)	GNSS Signal Processing	Earth Observation (EO)	Location Based Services (LoS)
1	SCORPION	X										
2	GALIRUMI	X										
3	GREENPATROL	X										
4	RECAP	X									X	
5	AUDITOR	X										
6	MISTRALE	X										
7	GEOPAL	X										
8	UNIFARM	X										
9	FieldCopter	X										
10	FIELDFACT	X										
11	BroadGNSS							X				
12	GAMMS					X						
13	RADIUS				X							
-	~~RAILGAP~~	-			~~X~~							-
14	PASSport			X								
15	ESRIUM					X						
-	~~GAMBAS~~	-		~~X~~								-
-	~~MOLIERE~~	-				~~X~~						-
16	GISCAD-OV						X					
17	DELOREAN		X									
18	ROOT							X				
-	~~PREPARE Ships~~	-		~~X~~								-
19	HELMET				X							
-	~~AMPERE~~	-					~~X~~					-
-	GRIMASSE		X									
20	GAUSS		X									
21	GEONAV IoT											X
22	CLUG				X							
23	HUUVER											X
24	SIA				X							
25	H2H			X								
26	SINSIN								X			
27	GIMS						X					
28	TransSec					X						
29	AIOSAT											X
30	HELIOS								X			
31	GALILEO 4 Mobility					X						
32	ENSPACE									X		

33	FLAMINGO											X
34	GOEASY											X
35	SARA								X			
36	ERSAT GGC				X							
37	PRoPART					X						
38	LOGIMATIC			X								
39	SKYOPENER		X									
40	STRIKE3									X		
41	STARS				X							
42	FOSTER ITS					X						
43	BLUEGNSS		X									
44	INLANE					X						
45	GRICAS								X			
46	MOBNET											X
47	5 Lives		X						x			
48	SAT406M			X								
49	EASY Pv						X					
50	LARA											X
51	spyGLASS			X								
52	InDrive					X						
53	RHINOS				X							
54	CaBilAvi		X									
55	PARADISE						X					
56	e-Airport		X									
57	BEYOND		X									
58	COREGAL						X					
59	ERSAT EAV				X							
60	mapKITE						X					
61	G-MOTIT					X						
62	GALENA					X						
63	GEO VISION											X
64	GHOST											X
65	JUPITER					X						
66	DEMETRA							X				
67	GMCA		X									
68	UKRAINE		X									
69	ELAASTIC											X
70	SUNRISE	X	x	x								
71	MEDUSE	X		x								
72	PANTHEON	X										
73	BACCHUS	X										
74	IOF2020	X										
75	NAVISAS	X										
76	ROMI	X										
~~77~~	~~VITIGEOSS~~	~~X~~									~~x~~	-
~~78~~	~~ENVISION~~	~~X~~	-	-	-	-	-	-	-	-	~~x~~	-

Table 12. Relevance of identified funded research projects relevant to AgriBIT

No	Project	Relevance to AgriBIT														
		GNSS (EGNOS)	Galileo	PPP-RTK	GNSS receiver	UAV/UAS	Geocoding assets	Extended Reality (ExR)	Precision positioning [cm]	Pest management	Machine Learning / AI	3D scanning / analysis	Internet of Things (IoT)	Autonomous systems	Robots	UGV
1	SCORPION	x	x	x					x					x	x	x
2	GALIRUMI	x	x	x	x				<20	x	x			x	x	x
3	GREENPATROL	x	X					x	x	X	x			x	X	x
4	RECAP	x							x		x					
5	AUDITOR	X		x	x				x						x	
6	MISTRALE	x	x		x	x			x						x	
7	GEOPAL	x							x					x	x	x
8	UNIFARM	x							x							
9	FieldCopter	x				x			x					x	x	
10	FIELDFACT	x	x		x											
11	BroadGNSS	x	x		x	x			x						x	
12	GAMMS	x	x	x	x				5		x			x	x	
13	RADIUS	x				x										
-	~~RAILGAP~~	~~x~~							~~x~~							-
14	PASSport	x				x								x	x	
15	ESRIUM	x	x						x					x	x	x
-	~~GAMBAS~~	~~x~~	~~x~~		~~x~~											-
-	~~MOLIERE~~	~~x~~	~~x~~		~~x~~		~~x~~									-
16	GISCAD-OV	x	x	x	x											
17	DELOREAN	x														
18	ROOT	x	x		x											
-	~~PREPARE Ships~~	~~x~~	~~x~~						~~x~~					~~x~~		-
19	HELMET	x	x		x	x			x					x		
-	~~AMPERE~~	~~x~~	~~x~~			~~x~~			~~<100~~		~~x~~	~~x~~			~~x~~	-
-	GRIMASSE	x	x		x											
20	GAUSS	x	x		x	x			x							
21	GEONAV IoT	x	x		x	x			< 100							
22	CLUG	x			x				x					x		
23	HUUVER	x	x			x			x			x		x	x	x
24	SIA	x	x		x				x							
25	H2H	x	x						x			x		x		
26	SINSIN	x	x		x											
27	GIMS	x	x		x									x		
28	TransSec	x	x						20		x	x		x		
29	AIOSAT	x	x						x		x			x		
30	HELIOS	x	x		x											
31	GALILEO 4 Mobility	x	x		x											
32	ENSPACE	x	x		x				x							
33	FLAMINGO	x	x	x	x				50							

34	GOEASY	x	x													
35	SARA	x	x			x			<10					x		
36	ERSAT GGC	x	x													
37	PRoPART	x	x	x					x		x			x		
38	LOGIMATIC	x	x											x	x	x
39	SKYOPENER	x	x			x										
40	STRIKE3	x			x											
41	STARS	x			x									x		
42	FOSTER ITS	x	x		x		x							x		
43	BLUEGNSS	x	x		x											
44	INLANE	x	x		x				x					x		
45	GRICAS	x	x						x					x		
46	MOBNET	x	x			x			<50							
47	5 Lives	x	x		x	x			x							
48	SAT406M	x	x						x							
49	EASY Pv	x	x			x	x		x					x		
50	LARA	x	x				x	x				x				
51	spyGLASS	x	x													
52	InDrive	x			x									x		
53	RHINOS	x	x													
54	CaBilAvi	x	x													
55	PARADISE	x	x	x	x				<50							
56	e-Airport	x	x		x						x			x		
57	BEYOND	x	x													
58	COREGAL	x	x	x		x			<100							
59	ERSAT EAV	x	x													
60	mapKITE	x	x			x	x					x			x	x
61	G-MOTIT	x	x		x				x							
62	GALENA	x	x				x									
63	GEO VISION	x	x			x										
64	GHOST	x	x		x		x				x			x		
65	JUPITER	x	x		x				150							
66	DEMETRA	x	x													
67	GMCA	x	x		x											
68	UKRAINE	x	x													
69	ELAASTIC	x	x													
70	SUNRISE	x	x													
71	MEDUSE	x														
72	PANTHEON	x		x		x			1					x	x	x
73	BACCHUS	x					x		2			x		x	x	x
74	IOF2020	?												x		
75	NAVISAS	x											x			
76	ROMI	x		x		x			x		x	x			x	x
~~77~~	~~VITIGEOSS~~	-					~~x~~		~~x~~	~~x~~						-
~~78~~	~~ENVISION~~	-	-	-	-	-	-	-	-	-	~~x~~	-	-	-	-	-

Projects funded by European Commission since Framework 7 () through to currently ongoing Horizon Europe have been scanned through in search for innovations that have led to the improvement of GNSS accuracies with special focus on ground receivers (for application on vehicles and stationary) and with primary domain application in Agriculture.

As it has been quickly realised the most of the project that required use of GNSS positioning, even to the highest accuracies, have NOT pursued custom development of receivers, merely limited themselves to the use of COTS solutions or even existing commercial products. This has allowed to narrow down the number of hits on ECAS project search engine from over eight thousands of such projects to a mere few hundreds of those.

The only exception have been some of the projects funded explicitly by GSA and then by EUSPA in the frames of the GALILEO sets of topics under FP7 and then Horizon 2020 frameworks. Those can be seen in **Table 10**. In few cases only, relevant projects have been identified to origin from other work programs, like ICT, SFS, SESAR, IoT etc. Nevertheless those have been in minority.

In order to offer AgriBIT the opportunity to establish inter-project liaisons in case of identifying possible opportunities for added value liaison, projects have also been classified as "ongoing" and those that have already concluded their grant agreements.

To distinguish projects with special orientation on (precision) Agriculture, their acronyms have been additionally shaded in green, thus indicating their attractiveness for either investigating in more detail their foregrounds (in case of those that finished) and/or for considering a working liaison with them. Since EUSPA/GSA has founded projects targeting diverse domains, not just Agriculture, additional classification has been provided in **Table 11** in case that their developments from other target markets might be nevertheless possibly re-used in AgriBIT.

The last **Table 12** provides a list of categories of possible relevance to AgriBIT, from multiple perspectives, which have been derived from the analysis of the user need and requirements in Task 2.1. From the perspective of Work Package WP3, the most relevant were categories related to positioning accuracy and usage scenarios. Those are expected to drive further development in Task 3.2 to building a received with the closest compliance to the needs of users in AgriBIT project.

NOTE: projects that have been crossed out are those that after closer analysis of their developments and results, have been deemed NOT directly relevant and/or NOT offering added value to AgriBIT.

8. Analysis of existing commercial GNSS solutions

A comprehensive analysis of commercial solutions from major brands has been analysed. Considering a vast amount of solutions available on the market, the focus has been made to ONLY such devices that are either explicitly targeting Agricultural applications (in this case irrespective of the performance metrics) and those that aim at achieving at least one (1) meter accuracy in autonomous mode and better than ten (10) centimetres in assisted (e.g. RTK) mode. Additionally SBAS accuracy of at least 30 centimetres was also an extra (optional) requirement, as long as assisted mode could offer a similar or better performance. The price tag was not an immediate condition during this desktop research, although indicative prices of relevant devices have been also investigated wherever they were available. The analysis came up with nearly 39 different devices, ranging from chipsets to COTS boards and fully qualified self-contained devices suitable for immediate application by end users. A full table of the most suitable devices with their parameters, characteristics and performance metrics has been provided in Table 13. List of identified commercial products relevant to *AgriBIT*

Table 13. *List of identified commercial products relevant to AgriBIT*

No	Product	Type	Company	Country	Price
1	Arrow Lite GPS	Receiver	Eos Positioning Systems	Canada (CA)	£2,660
2	Arrow 100/100+ GNSS	Receiver			
3	Arrow 200 RTK GNSS	Receiver			
4	Arrow Gold RTK GNSS	Receiver			£6,995
5	C94-M8P-3	Receiver	uBlox	Swiss (CH)	353 €
6	EVK-7	Eval. Kit			220 €
7	EVK-8/EVK-M8	Eval. Kit			220 €
8	EVK-M8QSAM	Eval. Kit			158.22 €
9	EVK-M8xCAM	Eval. Kit			158.22 €
10	EVK-M9	Eval. Kit			158.22 €
11	EVK-M10	Eval. Kit			
12	XPLR-M9	Explorer kit			
13	GPS-RTK Dead Reckoning pHAT	RASPI-4 HAT			270 €
14	IPESSA Classic	Receiver	Kindhelm	Finland (FI)	
15	IPESSA Tiny	Receiver			
16	IPESSA Nano	Receiver			
17	AP101 GNSS RTK/INS	Module	Absolute Precision	Estonia (EE)	
18	AP104 GNSS RTK/INS	Module			
19	AP105 GNSS RTK/INS	Module			
20	AP106 Multi-GNSS RTK/INS	Module			
21	BX992	Receiver	Trimble	US (corporate)	11,200 €
22	BX982	Receiver			11,100 €
23	ABX Two	Receiver			
24	BX940	Receiver			
25	OEM7	Dev. Kit	HEXAGON-NovaTel	Canada (corporate), NovAtel Europe (UK)	
26	OEM7600	Receiver			
27	OEM7700	Receiver			
28	OEM719	Receiver			
29	OEM7720	Receiver			

30	BY682 GNSS OEM	Board	Hunan Bynav Technology	China (CN)	139USD
31	C1 GNSS OEM (Fs/FD)	Receiver			
32	T1 GNSS (FS/FD)	Receiver			
33	EM-506	Eval. Kit	GLOBALSAT	SiRF StarIV	$40
34	SiRF Star IV 4e	Processor	Qualcomm	US & UK (EU)	
35	SiRFstar V 5e	Processor			
36	FieldBee RTK GNSS L1	Receiver	FieldBee	Netherlands (NL)	700
37	FieldBee RTK GNSS L2	Receiver			1300
38	Sxblue II + GNSS	Receiver	Sxblue	Canada (CA)	
39	Sxblue Platinum	Receiver			

Table 14. Constellation coverage for identified commercial GNSS products

No	GPS (US)	Galileo (EU)	BeiDou (CH)	Glonass (RU)	NavIC/IRNSS (India)	QZSS (Australia)
1	L1	n/a	n/a	n/a	n/a	n/a
2	L1	E1	B1	G1	n/a	n/a
3	L1,L2	E1	B1,B2	G1,G2	n/a	n/a
4	L1CA, L1P, L1C, L2P, L2C, L5	E1BC, E5a, E5b, E6	B1, B2, B3/B3i, B10C, B2A, B2B, ACEBOC	G1, G2, G3, P1, P2	L5	L1CA, L2C, L5, L1C, LEX
5	L1CA	-	B1I	L1OF	n/a	n/a
6	L1C/A	E1 B/C	B1I	L1OF	n/a	L1C/A, L1 SAIF
7	L1C/A	E1 B/C	B1I	L1OF	n/a	L1C/A, L1 SAIF
8	L1C/A	E1 B/C	n/a	L1OF	n/a	L1C/A, L1 SAIF
9	L1C/A	E1 B/C	B1I	L1OF	n/a	L1C/A, L1 SAIF
10	L1C/A	E1 B/C	B1I	L1OF	n/a	L1C/A
11	L1C/A	E1 B/C	B1I	L1OF	n/a	-
12	L1C/A	E1 B/C	B1I	L1OF	n/a	L1C/A
13	L1C/A, L2C	E1 B/C	B1I	L1OF	n/a	L1C/A
14	L1C/A, L2C	E1-B/C, E5b	B1I, B2I	L1OF, L2OF	n/a	n/a
15	L1C/A, L2C	E1-B/C, E5b	B1I, B2I	L1OF, L2OF	n/a	n/a
16	L1C/A, L2C	E1-B/C, E5b	B1I, B2I	L1OF, L2OF	n/a	n/a
17	L1/L2/L5	E1/E5a/E5b	B1/B2	L1, L2	L5	n/a
18	L1(C/A)/L2(C)/L5	E1/E5a	B1/B2	L1(C/A)/L2(C/A)	L5/S-band	n/a

19	L1(C/A)/L2(C)	E1/E5a	B1/B2	L1(C/A)/L2(C/A)	n/a	n/a
20	L1(C/A)/L2(C)	E1/E5a	B1/B2	L1(C/A)/L2(C/A)	L5	n/a
21	L1 C/A, L2E, L2C, L5	E1, E5A, E5B, E5AltBOC, E6	B1, B2, B313	L1 C/A, L2 C/A, L3 CDMA	L5	L1 C/A, L1 SAIF,L1C, L2C, L5, LEX
22	L1 C/A, L2E, L2C, L5	L1 BOC, E5A, E5B, E5AltBOC	B1, B2	L1 C/A, L2 C/A , L2 P, L3 CDMA	n/a	L1 C/A, L1 SAIF, L2C, L5
23	L1+L2	E1+E5b	B1, B2	G1+G2 FDMA	n/a	L1+L2
24	L1 C/A, L2E, L2C, L5	E1, E5A, E5B, E5AltBOC	B1, B2	L1 C/A, L2 C/A, L3 CDMA	L5	L1 C/A, L1 SAIF, L2C, L5
25	n/a	n/a	x	x	x	x
26	L1 C/A, L1C, L2C, L2P, L5	E1,E5 AltBOC, E5a, E5b	B1I, B1C, B2a, B2b, B2I	L1, L2, L3, L5	L5	L1 C/A, L1C, L2C, L5
27	L1 C/A, L1C, L2C, L2P, L5	E1, E5 AltBOC, E5a, E5b, E6	B1I, B1C, B2I, B2a, B2b, B3I	L1 C/A, L2 C/A, L2P,L3, L5	L5	L1 C/A, L1C, L2C, L5, L6
28	L1 C/A, L1C, L2C, L2P, L5	E1, E5 AltBOC,E5a, E5b, E6	B1I, B1C, B2I, B2a, B2b, B3I	L1 C/A, L2 C/A, L2P, L3, L5	L5	L1 C/A, L1C, L2C, L5, L6
29	L1 C/A, L1C, L2C, L2P, L5	E1, E5 AltBOC, E5a, E5b	B1I, B1C, B2I, B2a, B2b	L1 C/A, L2 C/A, L2P, L3, L5	L5	L1 C/A, L1C, L2C, L5
30	L1C/A、L2C、L2P	E1、E5b	B1I、B2I (BDS3: B1c 、B2a)	G1、G2	L5	L1C/A、L2C
31	L1CA/L1C,L2C, L2P,L5	E1, E5b/E5a	B1I, B2I/B3I (BDS3: B1I/B1C, B2a/B2b/B3I)	G1, G2	L5	L1CA/L1C, L2C, L5
32	L1CA/L1C, L2C, L2P,L5	E1, E5b/E5a	B1I, B2I/B3I (BDS3: B1I/B1C, B2a/B2b/B3I)	G1, G2	L5	L1CA/L1C, L2C, L5
33	L1	-	n/a	L1	n/a	n/a
34	L1	-	n/a	L1	n/a	n/a
35	L1	ready	n/a	L1	n/a	n/a
36	L1	-	n/a	L1	n/a	n/a
37	L1C/A L2C	E1B/C E5b	B1I B2I	L1OF L2OF	n/a	L1C/A, L2C
38	L1	E1	B1	G1	n/a	QL1
39	L1CA, L1P, L1C, L2P, L2C, L5	E1BC, E5a, E5b	B1, B2	G1, G2, P1, P2	n/a	L1CA, L2C, L5, L1C

***Table 15.** Operational performance metrics for identified commercial GNSS products*

No	Reliability [%]	TTFF (cold) [sec]	Reacquisition [sec]	Max speed	Speed Accuracy [m/a]	Heading accuracy [deg]	Max altitude [m]	Channels	Battery (Mains)	Battery life [hrs]	Charging time [hrs]
1	95	<60	<1	1607kmh			18288	12	Li-Ion	15	4
2	95	<60	<1	1850kmh			18288	158	Li-Ion	12/18	4
3	95	<60	<1	1850kmh			18288	372	Li-Ion	9	4
4	95	<60	<1	1850kph			18288	394	Li-Ion	11-12	4
5	99	26-29	1	500m/s	0.05	0.3	50000	72	USB-5V	-	-
6	99	30	1	500m/s	0.1	0.5	50000	56	USB-5V	-	-
7	99	26-45	1	500m/s	0.05	0.3	50000	72	USB-5V	-	-
8	99	26-30	1	500m/s	0.05	0.3	50000	72	USB-5V	-	-
9	99	26-45	1	500m/s	0.05	0.3	50000	72	USB-5V	-	-
10	99	24-29	2	500m/s	0.05	0.3	90000	-	USB-5V	-	-
11	99	24-29	1	500m/s	0.05	0.3	80000	-	USB-5V	-	-
12	99	24-29	2	500m/s	0.05	0.3	90000	-	USB-5V	-	-
13	99	24	2	500m/s	0.5	0.2	50000	184	USB-5/3.3V	-	-
14	-	24	2s	-	0.05	0.1	-		(6-32V)	n/a	n/a
15	-	35	2	-	0.05	0.1	-		(6-24V)	n/a	n/a
16	-	30	2	-	0.05	0.4	-		(5-24V)	n/a	n/a
17	-	-	-	-	0.15	2	-	-	(3.3/5V)	n/a	n/a
18	-	-	-	-	0.15	2	-	-	(3.3/5V)	n/a	n/a
19	-	-	-	-	0.15	2	-	-	(3.3/5V)	n/a	n/a
20	-	-	-	-	0.15	2	-	-	(3.3/5V)	n/a	n/a
21	99.9	45	2	515m/s	0.007	0.09	18000	2x336	(9-30V)	n/a	n/a
22	99.9	45	2	515m/s	0.07	0.09	18000	2x220	(9-28V)	n/a	n/a
23	99.9	60	2	515m/s	0.02	0.2	18000	240	(9-36V)	n/a	n/a
24	99.9	45	2	515m/s	0.07		18000	336	(9-30V)	n/a	n/a
25	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	-	n/a	n/a
26	99.9	39	1	515m/s	0.03	-	-	555	(3.3V)	-	-
27	99.9	39	1	515m/s	0.03	-	-	?	(3.3V)	-	-
28	99.9	39	1	515m/s	0.03	-	-	?	(3.3V)	-	-
29	99.9	39	1	515m/s	0.03	0.05	-	?	(3.3V)	-	-
30	-	45	1	-	0.05	0.2	-	-	(3.3V)	-	-
31	-	45	1	-	0.05	0.2	-	-	(3.25-3.45V)	-	-
32	-			-	0.05	0.2	-	-	(9-36V)	-	-
33	99	15-35	1	515m/s	0.01	0.01	18000	48	USB-4.5V	-	-
34	99	35	1	515m/s	0.01	-	18000	48	(3-3.6V)	-	-
35	99	25	0.1	515m/s	0.01	-	18000	48	(1.7-1.9V)	-	-
36		28	1	-	0.1	0.3	-		(12v-40v)	16	-
37	-	60	2	-	0.05	1	-	184	(9-36V)	8	-
38	95	60	<1	1850kph	-	-	18288	162	7.2V	>8	5
39	95	60	<1	1850kph	-	-	18288	372	7.2V	>12	6

Table 16. *SBAS performance metrics for identified commercial GNSS products*

No	Datum	Update freq. auto(RTK)	SBAS accuracy	Datum	WAAS (US)	EGNOS (EU)	GAGAN (India)	SouthPAN (Australia)	MSAS (Japan)
1	-	1/10/20Hz	<60cm	ITRF08	x	x	x	x	x
2	-	1/10/20Hz	<60cm	ITRF08	x	x	x	x	x
3	WGS-84, Epoch 2005.0	1/10/20Hz	<30cm	ITRF08	x	x	x	x	x
4	WGS-84, G1674	1/10/20/50Hz	<30cm	ITRF08	x	x	x	x	x
5	WGS-84	4/10/20Hz	-	-	-	-	-	-	-
6	-	10Hz	2m	-	x	x	-	-	x
7	-		2m	-	x	x	-	-	x
8	-		2m	-	x	x	x	-	x
9	-		2m	-	x	x	x	-	x
10	-	25Hz	2m	-	x	x	x	-	x
11	-	10Hz	2m	-	x	x	x	-	x
12	-	25Hz	2m	-	x	x	x	-	x
13	-	30Hz	-	-	-	-	-	-	-
14	-	<100Hz	-	-	x	x	x	-	x
15	-	<100Hz	-	-	x	x	x	-	x
16	-	<100Hz	-	-	x	x	x	-	x
17	-	1Hz (1/5/10Hz)	0.25m (0.5m)		-	-	-	-	-
18	-	1Hz (1/5/10Hz)	0.25m (0.5m)	-	-	-	-	-	-
19	-	-	-	-	-	-	-	-	-
20	-	1Hz (1/5/10Hz)	0.25m (0.5m)	-	-	-	-	-	-
21	-	<100Hz	0.5m (0.85m)	-	-	-	-	-	-
22	-	1/2/5/10/20/50Hz	0.5m (0.85m)	-	-	-	-	-	-
23	-	<50Hz	0.5m	-	-	-	-	-	-
24	-	<100Hz	0.5m (0.85m)	-	-	-	-	-	-
25	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
26	-	<100Hz	60cm	-	-	-	-	-	-
27	-	<100Hz	60cm	-	-	-	-	-	-
28	-	<100Hz	60cm	-	-	-	-	-	-
29	-	<100Hz	60cm	-	-	-	-	-	-
30	-	10, 20, 50Hz	-	-	-	-	-	-	-
31	-	5, 10Hz	x	-	-	-	-	-	-
32	-	5, 10Hz	x	-	-	-	-	-	
33	-	0.2-50Hz	-	-	x	x	x	-	x
34	WGS-84	1Hz	x	WGS-84	x	x	x	-	x
35	WGS-84	1Hz	x	WGS-84	x	x	-	-	x
36	-	1-10 (1-20) Hz	<1m	WGS-84	-	-	-	-	-
37	-	10Hz	-	-	-	-	-	-	-
38	-	1, 10, 20Hz	60cm	-	x	x	x	-	x
39	-	1, 10, 20, 50Hz	<30cm	-	x	x	x	-	x

Table 17. *Augmented performance metrics for identified commercial GNSS products*

No	Atlas H50	TTFF	Atlas H30	TTFF	Atlas H10	TTFF	RTCM	RTK	Range	IMU Support
1	-	-	-	-	-	-	<20cm	<5cm (L1)	-	
2	30-50cm	RT	15-30cm	4-5min	4cm	12-20min	<20cm	1-3cm	10km	
3	-	-	-	-	-	-	-	1-3cm	50km	
4	30cm	RT	15cm	4-5min	4cm	12-20min	-	8mm	50km	
5	n/a	-	n/a	-	n/a	-	x	2.5cm	?	
6	n/a	-	n/a	-	n/a	-	x	-		
7	n/a	-	n/a	-	n/a	-	x	-		
8	n/a	-	n/a	-	n/a	-	x	-		
9	n/a	-	n/a	-	n/a	-	x	-		
10	n/a	-	n/a	-	n/a	-	x	-	-	
11	n/a	-	n/a	-	n/a	-	x	-	-	
12	n/a	-	n/a	-	n/a	-	x	-	-	
13	n/a	-	n/a	-	n/a	-	x	20cm	-	x
14	n/a	-	n/a	-	n/a	-	3.x	0.01m	?	x
15	n/a	-	n/a	-	n/a	-	3.x	0.01m	?	x
16	n/a	-	n/a	-	n/a	-	3.x	0.01m	?	x
17	n/a	-	n/a	-	n/a	-	3.x	5mm (8mm)	?	INS
18	n/a	-	n/a	-	n/a	-	3.x	5mm (8mm)	?	INS
19	n/a	-	n/a	-	n/a	-	3.x	5mm (8mm)	?	INS
20	n/a	-	n/a	-	n/a	-	3.x	5mm (8mm)	?	INS
21	n/a	-	n/a	-	n/a	-	2.1-3.1	5mm (15mm)	50km	INS
22	n/a	-	n/a	-	n/a	-	2.1-3.1	8mm (15mm)	50km	-
23	n/a	-	n/a	-	n/a	-	2.3-3.2	8mm	50km	-
24	n/a	-	n/a	-	n/a	-	2.1-3.2	8mm (15mm)	50km	x
25	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
26	n/a	-	n/a	-	n/a	-	2.1-3.2	1cm	?	x
27	n/a	-	n/a	-	n/a	-	2.1-3.4	1cm	?	x
28	n/a	-	n/a	-	n/a	-	2.1-3.4	1cm	?	x
29	n/a	-	n/a	-	n/a	-	2.1-3.4	1cm	?	x
30	n/a	-	n/a	-	n/a	-	3.2	1cm (1.5cm)	?	x
31	n/a	-	n/a	-	n/a	-	3.2	1cm (1.5cm)	?	-
32	n/a	-	n/a	-	n/a	-	3.2	1cm (1.5cm)	?	-
33	n/a	-	n/a	-	n/a	-	x	-	-	x
34	n/a	-	n/a	-	n/a	-	x	-	-	
35	n/a	-	n/a	-	n/a	-				
36	n/a	-	n/a	-	n/a	-	3.1	<2.5cm	7km	-
37	n/a	-	n/a	-	n/a	-	3.3	10cm	-	-
38	x	-	x	-	x	-	2.3,3.2	5-20mm	-	-
39	x	-	x	-	x	-	2.3, 3.2	8mm	-	-

Table 18. *Interfaces used in identified commercial GNSS products*

No	Wi-Fi (range)	Bluetooth (range)	Ethernet	4G/LTE	Serial	SPI/I2C	GPIO	CAN bus	Antenna	USB
1	-	2.1+EDR (0.3-1km)	-	-	Option	-	-	-	SMA-F	2(B)
2	-	2.1+EDR (0.3-1km)	-		Option	-	-	-	SMA-F	2(B)
3	-	2.1+EDR (0.3-1km)	-	-	Option	-	-	-	SMA-F	2(B)
4	-	2.1+EDR (0.3-1km)	-	-	Option	-	-	-	SMA-F	2(B)
5	-	-	-	-	UART	both	-	-	SMA-F	?
6	-	-	-	-	UART	both	-	-	SMA-F	x
7	-	-	-	-	UART	both	-	-	SMA-F	x
8	-	-	-	-	UART	SPI	-	-	SMA-F	x
9	-	-	-	-	UART	both	-	-	SMA-F	x
10	-	-	-	-	UART	both	-	-	SMA-F	x
11	-	-	-	-	UART	I2C	-	-	SMA-F	x
12	-	-	-	-	UART	both	-	-	SMA-F	x
13	x	x	x	-	-	RASPI	x	-	U.FL	x
14	x	x	100T1	x	2	-	4	2		x
15		-	100T1	LTE-M/NB-IoT	1	-	2	2	TNC	x
16		v5.2	-	-	1	-	2	1	2xSME-F	-
17	-	-	-	-	2	-	-	-	-	1
18	-	-	1	-	3/2	-	-	0/1	-	1
19	-	-	1	-	3/2	-	-	0/1	-	1
20	-	-	1	-	3/2	-	-	0/1	-	1
21	-	-	100T1	-	2	-	-	1	2xTNC	1
22	-	-	100T1	-	3	-	-	1	TNC	1
23	-	-	100T1	-	2	-	-	-	2xTNC	v2
24	-	-	100T1	-	2	-	-	1	TNC-F	v2
25	n/a	n/a	100T1	n/a	5	n/a	n/a	2	TNC	2
26	n/a	n/a	100T1	n/a	5	n/a	n/a	2	RA MMCX-F	v2
27	n/a	n/a	100T1	n/a	5	n/a	n/a	2	MMBX-F	v2
28	n/a	n/a	-	n/a	3	n/a	n/a	2	MMBX-F	v2
29	n/a	n/a	100T1	n/a	5	n/a	n/a	2	MMBX-F	v2
30	n/a	n/a	100T1	n/a	3xUART	1xSPI	n/a	1	MMCX-K×2	x
31	n/a	n/a	100T1	n/a	3xUART	1xI2C	n/a	J1939	MMCK-Kx2	n/a
32	n/a	n/a	100T1	n/a	2xRS232	n/a	n/a	n/a	x2 (TNC-K)	n/a
33	-	-	-	-	UART	either	-	-	n/a	-
34	n/a	n/a	n/a	n/a	UART	both	n/a	n/a	n/a	n/a
35	n/a	n/a	n/a	n/a	UART	both	n/a	n/a	n/a	n/a
36	2.4GHz	2.1SPP	n/a	n/a	RS232	n/a	n/a	n/a	?	n/a
37	2.4GHz	n/a	n/a	n/a	RS232	n/a	n/a	n/a	?	n/a
38	n/a	v2.1	n/a	n/a	RS232	n/a	n/a	n/a	SMA-F	v2
39	n/a	v2.1+EDR	n/a	n/a	RS232	n/a	n/a	n/a	SMA-F	v2

__Table 19.__ Protocols and physical characteristics of identified commercial GNSS products

No	Protocols				Form factor		Durability					
	NMEA-183	RTCM SC-104	RAW data	Binary	Size [mm]	Weight [g]	Class	Temperature	Splash-proof	Dust-proof	Immersion	Agricultural?
1	x	x	RINEX	x	125x84x42	372	IP67	-40/85	x	x	30min/30cm	-
2	x	x	RINEX	x	125x84x42	372	IP67	-40/85	x	x	30min/30cm	-
3	x	2.x,3.x	RINEX	x	125x84x42	372	IP67	-40/85	x	x	30min/30cm	-
4	x	2.x,3.x	RINEX	x	125x84x42	372	IP67	-40/85	x	x	30min/30cm	-
5	x	MSG: 1,2,3,9	-	UBX	~70x50	-	-	-40/85	-	-	-	-
6	x	MSG: 1,2,3,9	-	UBX	105x64x26	-	-	-40/65	-	-	-	-
7	x	MSG: 1,2,3,9	-	UBX	105x64x26	-	-	-40/85	-	-	-	-
8	x	MSG: 1,2,3,9	-	UBX	100x60x26	-	-	-40/85	-	-	-	-
9	x	MSG: 1,2,3,9	-	UBX	100x60x26	-	-	-40/85	-	-	-	-
10	v4.1	RTCM 3.3	-	UBX	105x64x26	-	-	-40/85	-	-	-	-
11	v4.1	-	-	UBX	105x64x26	-	-	-40/85	-	-	-	-
12	v4.1	RTCM 3.3	-	UBX	60x32x15	-	-	-40/85	-	-	-	-
13	x	x		UBX	65x56	-	-	-40/85	-	-	-	-
14	x	3	?	x	-	-	IP68	-40/85	x	x	-	Yes
15	x	3	?	x	152x100x50	700	IP68	-40/85	x	x	-	Yes
16	x	3	?	x	50x55x22.6	300	IP68	-40/85	x	x	-	Yes
17	x	3	x	NTL	71x4 x10	28	-	-40/80	-	-	-	-
18	x	3	x	NTL	71x46x10	45	-	-40/80	-	-	-	-
19	x	3	x	NTL	71x46x10	40	-	-	-	-	-	-
20	x	3	x	NTL	71x46x10	40	-	-	-	-	-	-
21	x	2.1-3.1	x	x	185x93x43	760	IP67	-40/75	X	x	x	-
22	x	2.1-3.1	-	-	261x140x55	1600	IP67	-40/75	x	x	x	-
23	x	2.3-3.2	-	-	190x58x160	1270	IP67	-40/75	x	x	x	-
24	x	2.1-3.2	-	-	149x93x43	660	IP67	-40/75	x	x	x	-
25	n/a	n/a	n/a	n/a	?		n/a	n/a	n/a	n/a	n/a	-
26	x	2.1-3.2	NovAtel	x	55x35x11	31	MIL-810x	-40/85	x	x	n/a	-
27	x	2.1-3.4	NovAtel	x	46x71x8	31	MIL-810x	-40/85	x	x	n/a	-
28	x	2.1-3.4	NovAtel	x	46x71x11	31	MIL-810x	-40/85	x	x	n/a	-
29	x	2.1-3.4	NovAtel	x	46x71x8	29	MIL-810x	-40/85	x	x	n/a	-
30	x	3.2	x	x	71×46×11	32	-	-40/85	95%	-	n/a	x
31	x	3.2	-	-	71×46×11	20	-	-40/85	95%	-	n/a	x
32	x	3.2	-	-	135*152*73	1300	-	-40/85	95%	-	n/a	x
33	v3	-	-	-	30x30x10.7	16	-	-40/85	-	-	-	-
34	x	-	-	x	3.5x3.2x0.6	-	-	-40/85	95%	-	n/a	-
35	x	-	-	x	0.5x0.5x0.5	-	-	-40/85	95%	-	n/a	-
36	x	3.1	SkyTraq		150x75	200	IP67	-20/65	-	-	-	x
37	x	3.3	SkyTraq		150x75	200	IP67	-20/65	-	-	-	x
38	x	2.3,3.2	-	RINEX	141x80x47	487	IP65	-40/85	x	-	-	-
39		2.3,3.2	-	RINEX	141x80x47	481	IP67	-40/85	x	-	-	-

9. GNSS R&D targets

Following the analysis of the user needs and requirements from deliverable D2.1 and considering the current state of the art, both from commercial and scientific perspectives, a set of research and development goals have been derived for AgriBIT project. Those take special consideration for the needs of the Agricultural industry for precise geocoding of sensors and machinery as well as precise tracking, positioning and navigation of agricultural vehicles, especially in the field. Such stretched goals include also needs for applicability to both ground and aerial autonomous systems.

9.1. Stretched KPIs

A set of Key Performance Indicators (KPI) for the development of a custom GNSS receiver by RFSAT follows below. They distinguish between obligatory (must be satisfied) and optional (best effort).

Obligatory KPIs:

- GNSS constellations: Galileo (obligatory), GPS (essential), Glonass/BeiDou/AZSS/IRNSS (optional)
- Accuracy (autonomous): < 1m ± 25% (static) and < 1.5m ± 25% (dynamic)
- Accuracy (RTK): < 1cm ± 25% (static) and < 2.5cm (dynamic)
  RTK corrections from: EURIF-IP and/or Metrica in RTCM 2.x/3.x (messages TBC: 1, 2, 3 and 9)
- Accuracy (SBAS): < 30cm ± 25% (static) and < 60cm (dynamic)
- SBAS support: EGNOS (obligatory), WAAS/GAGAN/SouthPAN/KAAS/MSAS (optional)
- TTFF: preferably < 30sec and not more than 60sec (cold start), < 1sec (re-acquisition)
- Position update frequency: 1, 5, 10, 20, 50Hz Hz (up to 100Hz)
- Datum: WGS-84 (essential), other local ones TBC (optional)
- Antenna connector: SMA-F (preferable)
- Interfaces: Bluetooth (essential), Wi-Fi/USB/Serial (preferable) and Ethernet/CAN (optional)
- Output protocol: NMEA-0183 (essential), other (optional) e.g. NMEA-2000, raw, binary etc
- IP connectivity for RTK corrections (base-station): Wi-Fi (e.g. use Wi-Fi Access Point or smartphone as a modem via Wi-Fi Direct) and/or embedded Mobile Broadband (optional)
- Environmental durability: standard outdoor (IP67/IP68/MIL-810x for temperature, splash/dust-proof, no immersion required)
- OS supported for application: Android and MS Windows 10/11, iOS (not planned)
- Power supply: 5V DC via USB-C (preferable), current < 1A (preferable)
- Device configuration: e.g. via WEB browser from Android or Windows client connected via Bluetooth, USB or Wi-Fi
- Target form factor: 12/8/4cm (preferable) though the prototype is acceptable in larger sizes too
- Target weight: < 400g (commercial version), < 750g (prototype version)
- Target material price: < 500 Euros (commercial price) + up to 50% (offset for prototype version)

Optional KPIs:

- Max altitude: > 18.000m
- Max speed: < 500m/s i.e. exceeding speed of sound in air
- Power supply: USB-C 5V
- Battery power: Li-Ion
- Battery autonomy: > 8hrs (preferably 12hrs)

9.2. Current state of GNSS development

The original prototype of the GNSS receiver from RFSAT has been developed using CULP (Configurable Ultra-Low-Power) reference architecture in collaboration with the University of Westminster in the United Kingdom and has been "fabricated" on an FPGA development board. This device has incorporated a QUANTUMTM SA.45s Chip Scale Atomic Clock[1] (CSAC) oscillator, although a Rubidium version has also been investigated in order to improved clock drift performance. The RF front end incorporates all known GNSS signal bands, while multiple GNSS constellations have been already incorporated and validated. Desktop PC is used to off-load GNSS algorithms from FPGA for easier validation of new algorithms, e.g. anti-spoofing, interference-resilience, weak-signal detection etc.

The new and improved version is currently under development using uBLOX reference architecture as a base for the new design. The first integration has been already achieved and the preliminary performance tests are ongoing. The initial assessment of positioning already proves ability to offer 1-2cm accuracy with a form factor as shown in the figure below. Integration with EGNOS is still ongoing.

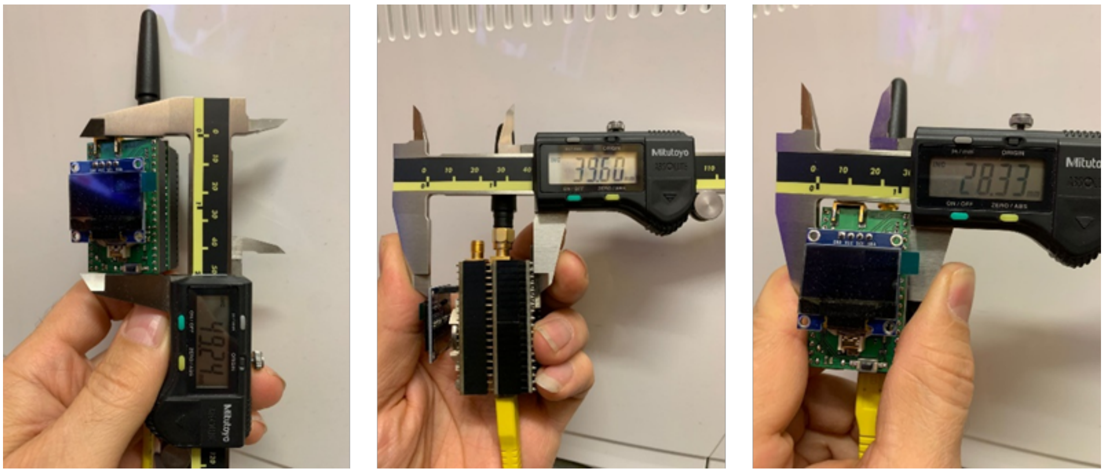

Figure 14. *The first prototype of a custom GNSS received by RFSAT*

The initial development performed by RFSAT has achieved to date the KPIs as shown in **Table 20**.

In general the most of the user needs and requirements have already been accounted for, with accuracies already reaching 1cm in stand-alone/autonomous mode and 2cm in dynamic/mobility tests. Nevertheless, further stress tests are still due to establish a stable baseline for field-like environments and on vehicles, being the standard expected usage scenario in AgriBIT.

The outstanding issue remains also battery consumption currently remaining at 6hrs using Lithium Ion rechargeable battery of 4500mAh capacity and 3.7V rating. This also assumes position update frequency at 5Hz, lower than the one requested by users of 30-50Hz. The increase of update frequency can be expected to drain battery even quicker. This is why further work will focus on power optimisation, aided with possible use of a larger capacity of the battery.

The full record of the development process and description of the developments following the submission of this deliverable will be reported in deliverable D3.2, due on month M12 for the COTS version and later on month M24 for the full custom version of the GNSS receiver built for AgriBIT.

[1] QUANTUMTM SA.45s Chip Scale Atomic Clock (CSAC): http://www.microsemi.com/products/timing-synchronization-systems/embedded-timing-solutions/components/sa-45s-chip-scale-atomic-clock

Table 20. *Current compliance with required KPIs*

No	Parameter	Requirement	Compliance
1	GNSS Constellations	Galileo (obligatory), GPS (essential), Glonass/BeiDou/QZSS/IRNSS (optional)	Galileo, GPS, Glonass, BeiDou, QZSS
2	Accuracy (autonomous)	<1m ± 25% (static) <1.5m ± 25% (dynamic)	OK
3	Accuracy (RTK)	<1cm ± 25% (static) <2.5cm (dynamic)	=>1cm (static) =>2cm (dynamic)
4	RTK corrections	EURIF-IP and/or Metrica in RTCM 2.x/3.x messages: 1, 2, 3 and 9	OK Any RTCM correction service
5	Accuracy (SBAS)	<30cm ± 25% (static) <60cm (dynamic)	OK
6	SBAS support	EGNOS (obligatory), and WAAS, GAGAN, SouthPAN, KAAS, MSAS (optional)	EGNOS, WAAS, GAGAN, MSAS, SDCM
7	TTFF	Cold start: < 30sec, not more than 60sec Re-acquisition: < 1sec	OK
8	Updates	1, 5, 10, 20, 50Hz	Up to 30Hz
9	Datums	WGS-84 (essential) other local ones TBC (optional)	OK
10	Antenna	SMA-F (preferable)	SMA and uFL
11	Communication interfaces	Bluetooth (essential) Wi-Fi/USB/Serial (preferable) Ethernet/CAN (optional)	OK
12	Output protocol	NMEA-0183 (essential) NMEA-2000, raw, binary (optional)	OK
13	RTK connectivity	Wi-Fi (e.g. Wi-Fi Access Point or smartphone as a modem via Wi-Fi Direct) embedded Mobile Broadband (optional)	OK: LAN (RJ45) and LORA
14	Durability	standard outdoor (IP67/IP68/MIL-810x for temperature, splash/dust-proof, no immersion required)	OK
15	OS supported	Android and MS Windows 10/11 iOS (not planned)	TBC
16	Power supply	5V DC via USB-C (preferable) current < 1A (preferable)	OK: 5-15V (DC), <1A
17	Battery power	Li-Ion with 10-12hrs autonomy	6hrs with Li-Ion, 3.7V, 4500mAh, 5Hz update
18	USB power	5V	OK
19	Device configuration	via WEB browser from Android or Windows client connected via Bluetooth, USB or Wi-Fi	OK Devices with WEB browsers
20	Form factor	12/8/4cm (preferable)	OK
21	Weight	< 400g (commercial version) < 750g (prototype version)	OK
22	Price	< 500 Euros (commercial price) up to 50% (offset for prototype version)	OK for multiband patch antenna included
23	Altitude	20.000m	80.000m
24	Speed	500m/s	OK

10. Requirements: Conclusion / Summary of GNSS specifications for AgriBIT.

Precision Agriculture is a crop management system that adapts inputs to the requirements of each part of the field. It assesses at the beginning the variability of the field and the crop using several technologies and sensors and then applies inputs to meet the crop requirements. This leads to reduced inputs and/or increased yields, improved resources use and reduced adverse effects to the environment. Additionally PA offers improved profitability and productivity of the farms and leads to improved sustainability of agriculture.

The usage of improved GNSS ground-based augmentation systems that provide centimetre accuracy in low cost is mandatory, especially for European small farmers which needs low cost high accuracy GNSS systems for gaining the benefits that being provided from PA with the usage of advanced positioning solutions.

The analysis made at the previous sections of this document, showed that a GNSS system for agriculture can have a big number of usages and more precisely:

- Recording
- Monitoring
- Mapping
- Sampling
- Tracking
- Navigation
- Positioning
- VR applications

Moreover, this analysis was used for defining, from the user side, the exact GNSS requirements by investigating the exact user needs in each one the usages of positioning solutions in PA. The results are summarized in **Table 21** which shows the GNSS requirements from the user side in terms of GNSS system connectivity and reliability.

Table 21. *GNSS requirements*

GNSS requirements	
Connectivity and data sharing	1. Compatibility and connectivity with: a. soil mapping sensors b. yield mapping sensors c. yield monitor displays d. NDVI ground sensors e. light bar driver assistance systems f. auto-steer systems g. VRA machineries h. UAV's i. UGV's 2. Real time data transferring in frequency of 20Hz 3. ISOBUS standard ISO 11783 support 4. NMEA 0183 support 5. RS232 and USB connectors

	6. Data extraction at the most common GIS protocols (KML, SHP, etc.)
Reliability	1. High precision a. Low Vertical error (less than 2cm) b. Low Horizontal error (less than 1cm) c. Accurate travel speed calculation (< ± 3%) 2. Widely available 3. Positioning recording and projection 4. Data recording in frequency up to 20Hz 5. IP67 protection 6. Ability to work through low visibility field conditions 7. Easily connectable and flexible

Additionally, this document summarises the analysis of the State of the Art of both commercial products availability on the market and the research output from European funded projects that could have relevance to AgriBIT from GNSS perspective. The main purpose was to ensure non-repeatability of work pursued in AgriBIT by RFSAT and AGENSO with respect to the development of the custom GNSS receiver for the users involved in the project. Since received performance (accuracy) has been identified as one of the most important metrics, research pursued not only in the domain of Precision Agriculture, but all possible receivers with specs matching user needs in Task 2.1 have been also investigated and analysed. As a results we came up with a list of over 39 of commercial products that show possible compliance with user needs and over 78 EU-funded projects (18 of which are still ongoing) that might offer opportunities for re-use of their results and/or establishing working collaboration.

As it came up, there are a number of commercial products with technical specs matching AgriBIT target specifications, nevertheless many of which are either excessively expensive or their form factor is too bulky. As presented in section 9 on the example of the 1st prototype of a custom GNSS being developed by RFSAT, the form-factor and expected cost, as well as price to customer, are likely to be advantageous over currently available products. It is also worth mentioning here that technologies used in developing such a receiver have shown added value over the identified innovations, giving us a good feeling that work in Task 3.2 is progressing towards producing a seriously innovative solution.

List of Abbreviations

Abbreviation	Explanation/Definition
BeiDou	Chinese for “the Big Dipper”
AGPS	Augmented Global Positioning System
CAN	Controller Area Network
CDMA	Code Division Multiple Access
CSA	Coordination and Support Action
CSR	Corporate Social Responsibility
CSAC	Chip Scale Atomic Clock
DC	Direct Current
DGPS	Differential Global Positioning System
DOP	Dilution of Precision
EDR	Endpoint Detection and Response
ECEF	Earth-fixed coordinate system
EGNOS	European Geostationary Navigation Overlay Service
EO	Earth Observation
EUSPA	European Union Agency for the Space Programme
FDMA	Frequency Division Multiple Access
FPGA	Field-Programmable Gate Array
GeoJSON	Geospatial Java Script Object Notation
GLONASS	Global Orbiting Navigation Satellite System
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GSA	European Agency for Global Navigation Satellite Systems
IA	Innovation Action
ICT	Information and Computer Technology
ISO	International Standardisation Organisation
IT	Information Technology
KAAS	Korea Augmentation Satellite System
LAN	Local Area Network
MIL	US defence military standard, "MIL-STD" or "MIL-SPEC"
MMBX-F	Micro Miniature Board Connector (female)

MMCX-F	Micro-Miniature Coaxial Connector (female)
MSAS	MTSAT Satellite Augmentation System
MSA	Mobile Station Assisted
MSB	Mobile Station Based
MTSAT	Multifunction Transport Satellite
nAvStAr	nAvigation System timing And ranging
NDVI	Normalized Difference Vegetation Index
NMEA	National Marine Electronics Association
PA	Precision Agriculture
PRN	Property Reference Number
QZSS	Quasi-Zenith Satellite System
RIA	Research and Innovation Actions
RINEX	Receiver Independent Exchange Format
RAM	Random Access Memory
ROM	Read Only Memory
RTK	Real-Time Kinematic
SBAS	Satellite-Based Augmentation System
SDCM	System for Differential Corrections and Monitoring
SMA-F	SubMiniature version A (female)
SoA	State of the Art
SPI	Serial Peripheral Interface
SPP	Sequenced Packet Protocol
TNC-F	Threaded Neill–Concelman (female)
TTFF	Time To First Fix
UART	Universal Asynchronous Receiver Transmitter
UC	Use Case
USB	Universal Serial bus
UV	Unmanned vehicle
VRA	Variable Rate Application
WGS-84	World Geodetic System 1984

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Internal Deliverable Review Form

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Topic	Answer	IF "No", classify as "Major" or "Minor" issues	Comments
1. Is the content and structure of the deliverable in accordance with the DoA?	Yes		
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3. Is the content of the deliverable useful for the subsequent work on the project?	Yes		
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4.1. Does it need formatting adjustments?	No		
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