Global positioning systems are relatively new technologies when it comes to applications in agriculture. Applications in tractor guidance, variable rate supply of chemical inputs and field monitoring of crop yield were recently tested using GPS. This article studies the basic concepts of GPS as they apply to agricultural production and provides a detailed analysis of the recent developments in this area with a focus on functionality and efficiency.

Over the past 30 years agricultural machinery has reached high technical standards in order to improve agriculture production. Precision agriculture or satellite agriculture is a highly effective farming management method that focuses on intra-field variation in order to optimise agriculture returns while conserving environmental resources. It relies on new technologies such as the Global Positioning System, global navigation satellite systems, augmentation systems, and geospatial tools such as GNSS receivers. Satellite technology and augmentation systems, such as the European Geostationary Navigation Overlay Service (EGNOS), have made a major contribution in improving agriculture productivity. Satellite tracking, ploughing monitoring, harvesting, distribution of fertiliser, herbicide and water irrigation are some of the applications of positioning technologies in agriculture to improve productivity. Tested in several countries, this practice revealed important economic and environmental benefits.

**Evolution from GPS system to global navigation satellite system**

**The US GPS system.**

The global navigation satellite system (GNSS) is the worldwide satellite constellation, supported by several augmentation systems and user equipment [1]. The GPS satellite system is the first global navigation satellite system, developed by the United States of America in early 1970 [2]. From the 57 GPS satellites placed in orbit (including spare satellites in case of failure), 31 are currently operational. These satellites are maintained within 24 circular orbital planes inclined 55° with respect to the equator plane [1]. The system currently provides two user services: (i) the Standard Positioning Service (SPS), open to civil users is available for civil applications such as agricultural practice and farming, and (ii) the Precision Positioning Service, restricted to authorised users such as the United States military and their allies. The first GPS accuracy for civil users was 13 m for horizontal positioning and 22 m for vertical positioning [1]. This precision did not include errors due to atmosphere, multi path or user equipment. The ground network that controls, monitors and commands GPS satellites is called the control segment (CS) and comprises a master control station (MCS), a global set of monitoring stations and ground antennas. This control segment recently went through two important improvements with the addition of a number of new monitoring stations, taking the total number of 6 to 14 [2] and the upgrading of the master control station completed in 2007 that transformed the system from the IBM mainframe computer system to a more modern system based upon a distributed Sun Workstation Configuration.

**The Russian GLONASS system**

Completed about twelve years after the American GPS system, in October 1992, the Russian GLONASS satellite system was only used by the Russian military for years and was only opened to civilians in 2007 [3]. Comparable to the American Global Positioning System, the Russian navigation system is a radio-based satellite navigation system providing location and time information worldwide and provides support to military, civil and commercial applications.

A total of 24 GLONASS satellites are actually operational with the latest satellite placed into space on 26 April 2013 with an inclination of 64.8° and an altitude of 19 100 km [3]. The system broadcasts two types of navigation signals: (i) the standard accuracy signal mainly available to civil users worldwide which is generated using a 0.511 MHz chipping rate and (ii) the high accuracy signal restricted to the Russian Ministry of Defence and authorised entities which has a signal of 5.11 MHz chipping rate. On 18 May 2007, Russian president, Vladimir Putin signed a decree reiterating the offer to provide GLONASS civil signals free of direct users fees, to the world [2]. The GLONASS system comprises a ground control segment with ten monitoring stations distributed through Russia and additional facilities to command and control the satellites.

**The European Galileo system**

The Galileo system is the European navigation system designed for civil and commercial applications. The Galileo system is interoperable with the other navigation systems. This interoperability attribute offers to all users the benefits of more satellite availability for redundancy and high accuracy. The constellation of the Galileo system is currently four satellites placed in three Medium Earth Orbital (MEO) planes inclined at 56° to the equator at about 23 000 km altitude. Each plane has one active spare of satellite to cover in case of any failed satellite in that plane. The European system offers horizontal and vertical measurements within 1 m precision. The system is supported
The Chinese Compass system

The Beidou Navigation System is the first Chinese navigation system which provides feedback to the users. It is considered a major upgrade in the existing GPS, GLONASS and COMPASS navigation systems, which do not overlap or continuous to frequencies used by GPS and GLONASS systems. In addition, Galileo provides an exceptional global search and rescue (SAR) function. In fact Galileo satellites are equipped with a transponder which relays distress signals from the user’s transmitter to the Rescue Co-ordination Centre, which then initiate the rescue operation. At the same time, the system provides a signal to the users, informing them that their situation has been detected and that help is on the way. This function is considered a major upgrade in the GNSS constellation compared to the existing GPS, GLONASS and COMPASS navigation systems, which do not provide feedback to the users.

The first Chinese navigation system which consists of two separate satellite constellations. The first constellation called Beidou1 is a limited test system of four satellites that has been operating since 2000. The first satellite, BeiDou-1A, was launched on 30 October 2000, followed by BeiDou-1B on 20 December 2000. The third satellite, BeiDou-1C was put into orbit on 25 May 2003. In February 2007, the fourth and also the last satellite of BeiDou-1 system, the BeiDou-1D was launched into space. From 2008 the Chinese government decided to offer the BeiDou1 service to civil users with an accuracy of 10 m. The second constellation called Beidou2 or Compass navigation system is a constellation of seven satellites operating since 2007. In April 2007, the first BeiDou-2 satellite called the Compass-M1 was placed into orbit. The second satellite Compass-G2 was launched on 15 April 2009. On 17 January 2010, the constellation’s third satellite Compass-G1 was placed into orbit. On 2 June 2010, the fourth satellite was successfully put into space. The fifth satellite was launched into space from Xichang Satellite Launch Centre by an LM-3I carrier rocket on 1 August 2010. On 1 November 2010, the sixth satellite was sent into orbit by the LM-3C carrier rocket. Another satellite, the Compass IGSO-5 satellite, was launched from the Xichang Satellite Launch Centre by a Long March-3A carrier rocket on 1 December 2011. The system also provides low-rate bidirectional communications and differential GPS/GLONASS services. The Compass system offers two services to users: An open service providing an accuracy of 10 m and an authorised service, only intended for entities authorised by the Chinese government such as the Chinese military. The Compass Navigation Satellite System is a CDMA-based system with DSS signals on four carrier frequencies: the 1207,14 MHz frequency shared with Galileo E5b, the 1268,52 MHz frequency shared with Galileo E6, the 1561,098 MHz frequency (E2) and the 1589,742 MHz frequency (E1). The receiver power level of Compass navigation satellite system was reported stronger than the typical received GPS power level [1]. The international cooperation between China and the European Union with regards to global navigation satellite technologies materialised in October 2004 with the signing of an agreement for the Galileo project. China invested €230-million in the European Galileo project. By April 2006, eleven cooperation projects within the Galileo framework were signed between China and the European Union.

GNSS augmentation systems

Augmentation systems are used to increase the accuracy of the basic GNSS signals by transmitting corrections to the GNSS receivers either via satellite or terrestrial radio. For instance, instead of a normal GPS accuracy of 4,5 m, an augmented system can pinpoint this location measure to an accuracy of 0,6 m.

Ground-based augmentation systems

A ground-based augmentation system (GBAS) uses radio towers to transmit corrections to the GNSS receivers. There are hundreds of ground-based augmentation systems around the world transmitting signals in a wide variety of frequencies ranging from...
Fig. 3: A semi-automated soil sampler equipped with a GNSS receiver. Each soil sample is associated with its geographical location.

Fig. 4: Examples of field traffic patterns that a vehicle equipped with GNSS can follow [7]. Each pattern is characterised by an alignment of points with known geographical coordinates.

162.5 KHz to 2.95 MHz. In the United States of America, the Nationwide Differential GPS (NDGPS) system is an example of an augmentation system. Ground-based augmentation systems receive signals from the GNSS constellation and compare the received values with their accurately surveyed locations and the differences are used to calculate corrections of the GNSS signals. The corrections are then conveyed either to the GNSS receivers via geostationary satellites or terrestrial radio. An illustration of a ground based augmentation system is shown in Fig. 1.

Satellite-based augmentation systems
A Satellite-based augmentation system provides differential corrections, integrity parameters and ionospheric data over a given region. This system consists of a ground network of monitoring stations that collect GNSS measurements. The receivers in the ground network for the case of the US GPS system are capable of tracking the GPS L1 and L2 C/A and L2 P(Y) code signals in order to determine the electron content of the ionosphere integrated along the signal path from the visible satellites. Semi codeless processing techniques are used to track the encrypted P(Y) code signals [4]. Some satellite based-augmentation systems ground networks are capable of monitoring GPS and GLONASS L1 signals. Error corrections and integrity data are then computed by a centralised facility. This information is then broadcast to the end users through a geostationary satellite link. Only three satellite augmentation systems are actually operational: The European Geostationary Navigation Overlay Service (EGNOS), the United States Wide Area Augmentation System and the Japanese Multifunction transport Satellite system MTSat. Fig. 2 shows an illustration of the concept of a satellite-based augmentation system.

Three other satellite augmentation systems are at different stages of construction including the Nigerian Communication Satellite (NIGCOMSAT), the Chinese Satellite Navigation Augmentation System (SNAS) and the Indian GPS/GLONASS and GEO augmented Navigation (GAGAN) (Groves, 2008).

Applications of GNSS in agriculture.
Decision making is an important step in the management of agricultural production. GNSS can be a useful support system for tactical decision making to enable the farmer to evaluate a multitude of different scenarios based on all the variables influencing his agricultural activities [5]. The use of yield sensors developed from the new technologies, combined with GNSS receivers, has been gaining ground ever since [6]. This practice allows, for example, farmers to vary the rate of fertilisers across the field according to the need identified on GNSS guided maps.

Agricultural vehicles guidance
In addition to location based information, GNSS technologies make possible the auto guidance of agriculture vehicles. Auto guidance is the guidance of vehicles using satellite-based positioning equipment as illustrated in Fig. 3. This technique reduces skips and overlaps, lower operator fatigue and enhances the ability to work in poor visibility conditions.

An important feature of GNSS is the ability to accurately follow particular traffic patterns and provide effective feedback so that the operator or auto-steer system can appropriately respond. Most systems can effectively perform straight-line patterns (linear swathing), and many can follow contours and other field features as illustrated in Fig. 4.

Management of crop health
Remote sensing devices are devices that are able to collect data from distances. This is achieved by light reflectance collected by instruments in airplanes, orbiting satellites or hand-held devices. Remotely sensed data provide a valuable tool for evaluating crop health. Overhead images are useful to detect plant stress related to moisture, nutrients as well as crop disease. The real time information provided by these sensors is valuable for making management decisions in order to improve agriculture profits. Fig. 5 shows an example of an affected area on an image provided by GNSS satellites.
Fertilisers and soil management

Global navigation satellite systems can be used to determine in which precise part of an agricultural field a tractor has collected soil samples for fertility analysis. Resulting information about the variability of soil fertility within a field is essential for decision support. Soil information can be obtained by physically obtaining samples throughout fields and analysing these samples at a laboratory or through the use of the on-the-go-soil sensors mounted on a tractor [8]. The application of chemicals and fertilisers in appropriate proportions is of economic and environmental concern to the farmers as a consequence, results of soil analysis in combination with information about the agricultural returns can form the foundation for planning future fertilisers management for specific types of crops. Using a GNSS positioning receiver along with crop health information identified on satellite imagery, a farmer is able to apply pesticides in a safer manner. In fact, the spraying equipment can be pre-programmed to automatically turn off when it reaches a certain location on the agricultural field. Additionally, farmers can pre-program the rate of fertilisers to be applied at specific locations of the field so that only the amount determined by the soil studies is applied at a variable rate from one area to the other. This saves money and allows for safer use of farming resources and minimises environment pollution.

More over, the use of technologies such as the Mobil Sensor Platform (MSP) with mounted GNSS receiver to study soil pH, as illustrated in Fig. 6, can enable the identification of field areas with acidic soils. The measurements collected can be used to evaluate the amount of fertiliser needed to raise the soil pH to a suitable level for a specific type of crops. The mounted GNSS receiver can also provide elevation data of the area and enable the identification of field areas with spatially variable soil water-holding capacity.

In addition, maps of soil mechanical resistance can expose field areas not potentially appropriate for crop growth [8]. Both soil compaction and low moisture content theoretically cause high soil strength. Using precise location information associated with different soil types would lead to higher yields as a consequence of better management of agriculture resources, involving low production cost. Fig. 7 illustrates a prototype integrated soil physical properties mapping system used to study soil resistance.

Effective seed management

Certain agricultural seeds perform best when placed at spacing that allows the plants to benefit at maximum from the sunlight and soil moisture. A computerised soil map of a field on a computer fitted on the tractor along with a GNSS receivers can inform farmers where they are in the field, allowing the adjustment of seeding according to suitable spacing. Combining positional data with soil texture, organic matter, and soil moisture information can enable the farmer to vary the seeding rate according to the soil condition. For example, one would plant fewer seeds in sandy soil than in silt loam soils areas because of less available moisture [8]. Since soils vary even across an individual agricultural field, the ability to change seeding rates as one goes across the field allows the farmer to maximise this seeding rate according to the soil conditions.

Benefits of satellite agriculture

Traditional sampling techniques such as whole-field sampling to assess fertility levels have shown limits as they do not always guarantee a perfect representation of fertility variation across the field [8]. In contrast, regularly-spaced grid soil sampling provides data that better characterises the variability of soil fertility. The technique has shown promising results in terms of reduction of pollution from agricultural chemicals [8]. This is possible by linking each fertility zone to respective geographical location to facilitate application of fertilisers more efficiently as illustrated in Fig. 8.

On-the-go agricultural mapping, semi-automated agricultural vehicle guidance have revealed great economic benefits around the world. In Texas for example, the technique resulted in higher cotton yields and higher net returns compared to traditional agricultural methods. Moreover, the application of GNSS in agricultural practice has resulted in a better management of pesticides and higher cotton yields in Georgia, United States of America. In Colorado, the technique led to better management of nitrogen in corn agriculture compared to traditional practice. In Nebraska,
studies during 2004 – 2005 by the University of Nebraska showed savings in production cost of US$9.54 per acre when integrating GNSS in agriculture compared to traditional methods. With improvement in the quality of positioning technologies the saving increased up to US$26.38 per acre when the study was repeated in 2008. Similarly, the integration of positioning technologies in agriculture results in more accurate soil pH mapping [8]. Tested on a Kansas agricultural field, the approach produced a very accurate pH map compared to the conventional 2.5 acre grid sampling technique. In fact the traditional 2.5 acre grid sampling produced inaccurate mapping results in which some areas with neutral and acid pH could not accurately be geographically located as illustrated in Fig. 9.

A study of the benefits of integrating GNSS technologies in agriculture undertaken by Bowman [9], revealed a 68% increase in farm gross margins resulting from a better management of agriculture resources, 67% reduction in farm labour costs as a consequence of automation of agriculture vehicles guidance, 90% reduction in soil erosion caused by agriculture practice, 93% reduction in nitrogen loss through runoff and 52% reduction in CO2 emissions, in comparison to traditional techniques employed in previous years.

**Conclusion**

This article presented the basic concepts of global navigation satellite systems as they apply to agriculture practice and provided an analysis of some of the recent developments in this area with a focus on functionality and efficiency. The use of GNSS in agriculture enables a more effective use of agricultural resources including crops, pesticides, fertilisers, irrigation water as well as a good management of soil through tillage and soil fertility analysis. More effective use of agricultural resources means greater crop return while minimising environmental impacts of chemicals. Precision agriculture addresses economic and environmental issues that affect agriculture practice today. The technique increases the economic margins of crop production by improving yield and reducing input costs [10]. The integration of GNSS technologies in agricultural practice reduces manpower and as a result enhances productivity due to automatic agriculture vehicle guidance. Application of GNSS in agriculture enables targeted application of fertilisers and pesticides reducing the risks of pollution from agro-chemicals [10]. Moreover, precision agriculture reduces erosion risks because it enables the study of soil resistance and moisture that can reveal areas with high risk of soil erosion. Precision agriculture also enables a more reasonable use of water resources as irrigation farming is the largest consumer of water resources worldwide. Concentrating on efficient use of water for agricultural purposes is very important. Precision agriculture enables farmers to reduce their consumption of water by identifying areas in agricultural fields characterised by high soil moisture that would need less irrigation water. In Australia, precision agriculture has reduced carbon emission in recent years [11]. Precision agriculture enables farmers to identify problems in their fields that are difficult to identify by using traditional methods.

**References**


Contact Guy Blanchard Ikokou, University of Cape Town, ikokou@yahoo.fr