International Journal of Agriculture, Environment and Biotechnology
Citation: *IJAEB*: **18**(01): 67-73, March 2025
DOI: 10.30954/0974-1712.01.2025.10

ASSOCIATION FOR AGRICULTURE ENVIRONMENT AND BIOTECHNOLOGY

REVIEW PAPER

Application of GNSS In Agriculture and Horticulture

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Paper No. 1205 **Received:** 06-01-2025 **Revised:** 25-02-2025 **Accepted:** 02-03-2025

ABSTRACT

Precision agriculture and horticulture have been transformed by Global Navigation Satellite Systems (GNSS), which make it possible to precisely monitor, map, and manage agricultural fields. From crop management and irrigation to yield monitoring and soil sampling, GNSS guarantees accurate and effective resource use. Variable rate technology (VRT), nutrient management, and soil moisture prediction have advanced uses for GNSS technologies such as Real-Time Kinematic (RTK) and interferometric reflectometry. By integrating with robotics and remote sensing, GNSS improves autonomous operations and environmental monitoring in orchards and vineyards. With its unmatched accuracy, efficacy, and affordability, GNSS is also essential for land surveying and planning. Innovation is being fueled by the combination of GNSS with other technologies such as UAVs, LiDAR, and GIS, which is converting conventional farming methods into sophisticated, sustainable systems. This study emphasizes the various ways that GNSS is used in horticulture and agriculture, highlighting how important it is to the advancement of contemporary farming methods.

HIGHLIGHTS

- GNSS enables precise field mapping, crop management, and resource optimization.
- RTK and reflectometry support VRT, nutrient, and soil moisture management.
- Integration with UAVs, LiDAR, and robotics enhances automation and monitoring.
- GNSS is key to smart, sustainable, and efficient modern farming.

Keywords: GNSS Technology, Precision Agriculture, Artificial intelligence, Farm management

Historically, manual labor and conventional estimation methods have been used for planning and management in horticulture and agriculture. These industries have seen substantial changes over time, moving from manual and animal-powered processes to mechanization, the Green Revolution's breakthroughs, and, more recently, precision agriculture (Sishodian *et al.* 2020). In its broadest sense, precision agriculture refers to a management system that makes use of cutting-edge information, communication, and navigation technologies. The Global Positioning System (GPS), Geographic Information Systems (GIS), and Global Navigation Satellite Systems (GNSS) are essential components of this strategy since they allow for the precise mapping of soil and vegetation properties as well as the determination of field boundaries.

Global positioning, navigation, and timing services are provided by the GNSS constellation of satellites, which functions regardless of the time of day or the weather. Although the most well-known GNSS is GPS, which was created in the United States, other systems like Russia's GLONASS, Europe's Galileo, China's BeiDou, Japan's QZSS, and India's IRNSS all make a substantial contribution to global navigation capabilities.

How to cite this article: Pawar, A.T., Pathak, S.V. and Shahare, P.U. (2025). Application of GNSS In Agriculture and Horticulture. *Int. J. Ag. Env. Biotech.*, **18**(01): 67-73.

Source of Support: None; **Conflict of Interest:** None

By providing accurate direction, GNSS technology is essential to precision agriculture, helping to maximize field operations like planting, fertilizing, and harvesting. This accuracy decreases the influence on the environment, lowers input prices, and improves resource efficiency. To ensure that fertilizers and insecticides are administered only where necessary, GNSS, for example, makes it easier to create precise field maps that support variable rate technology (VRT) for input application (Gebbers and Adamchuk, 2010).

Traditional farming techniques have been transformed into high-tech, effective systems by the use of GNSS into horticultural and agricultural processes. This change increases profitability and decreases waste. GNSS facilitates a thorough understanding of field variability by supplying real-time data for yield monitoring, field mapping, and other spatial analysis. This understanding guides tailored management plans and maximizes resource usage (Saiz and Rovira, 2020). GNSS data facilitates the production of prescription maps when combined with yield maps, soil maps, and other spatial data. According to Ammoniaci *et al.* (2021), these maps direct VRT equipment to apply inputs at varied rates suited to certain field conditions. Furthermore, depending on the receiver technology, geodetic-quality networks can now deliver a variety of in situ observations because to developments in GNSS technology. The uses of GNSS in agriculture have been further expanded by methods like GNSS Reflectometry (GNSS-R), which uses two antennas to acquire waveforms (one zenith-oriented and one surface-oriented), and GNSS Interferometric Reflectometry (GNSS-IR), which uses a single antenna to analyze signal strength using the signal-to-noise ratio (SNR) (Zavorotny *et al.* 2014; Larson, 2016).

Application of GNSS in Precision Agriculture and Horticulture

GNSS technology is widely used in precision agriculture. The following are some common applications:

Yield Monitoring and Mapping

Using GNSS-enabled path tracking in conjunction with agricultural equipment like drones, tractors, or harvesters, yield monitoring and mapping entails the georeferenced collection of data during crop harvesting. Grain yield data, yield maps, and other pertinent metrics are gathered during this process (Redhu *et al.* 2022). A thorough record of all the agronomic, climatic, and management factors influencing crop performance over a growing season is provided by yield maps. Farmers can create maps that show differences in productivity across various field regions by using GNSS data combined with yield monitors. This gives them information about crop production and possible income. When yield data from several seasons are analyzed over time, similar spatial yield patterns can be found (Blackmore *et al.* 2003; Leroux *et al.* 2018; Dela *et al.* 2021).

Yield maps are categorized into four types:

1. **Inference Maps:** These maps incorporate yield estimates into pre-existing delineations without altering the base map.
2. **Prediction Maps:** These utilize predictive modeling functions to estimate yields.
3. **Interpolation Maps:** These estimate yield values between measured data points using interpolation techniques.
4. **Aggregation Maps:** These are derived from measured data or accumulated datasets for mapping purposes (Shome and Upadhyay, 2020).

In order to monitor sugarcane yield in Brazil, Magalhães and Cerri (2007) integrated a mass flow sensor, GPS receiver, and data gathering system into a CASE 7700 harvester. For the purpose of gathering data, the 42.7-hectare study area was split up into 20 m² cells. For every cell, variables including harvester speed, time, latitude, longitude, yield, harvested area, and measured weight were noted. A digital sugarcane yield map that shows spatial yield variations ranging from 6 to 150 t/ha was made using GIS software (ArcGIS 8.3).

Anjom *et al.* (2018) created a Real-Time Kinematic GNSS (RTK-GNSS) receiver in conjunction with an inexpensive strawberry yield sensing system. As a picking cart moved across the field, the system recorded fruit weights and geo-coordinates to map yield. 95.2% accuracy was attained by the device under field settings.

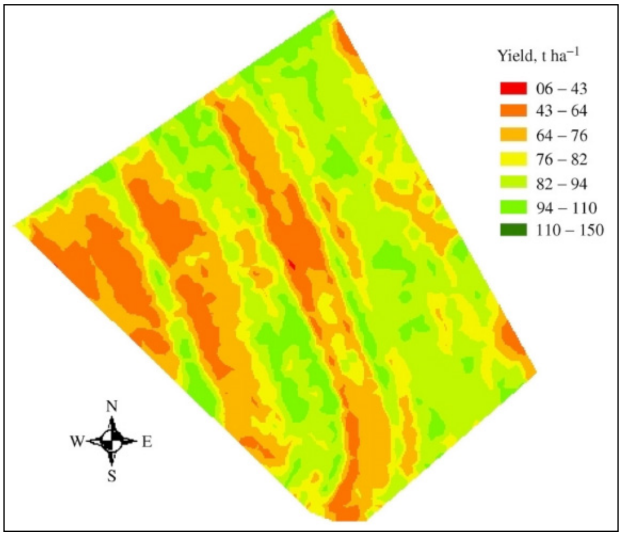

Fig. 1: Sugar cane plantation yield map

Konstantinovic *et al.* (2008) looked at the detection of sugar beets underground using ultra-wideband (UWB) radar devices coupled with GNSS. The system's potential for real-time yield estimation was demonstrated by field experiments that showed a correlation between sugar beet mass and backscattered radar energy of over 80%.

In addition to offering a thorough depiction of crop production, yield maps facilitate sophisticated decision-making. Farmers can benefit greatly from these maps by using them to conduct on-farm experiments, improve input management, and create profitability maps. For both annual and perennial horticulture crops, yield mapping and monitoring systems are still in their infancy despite persistent regional heterogeneity in crop yields. However, they have enormous potential to improve these systems' profitability and resource efficiency (Longchamps *et al.* 2022).

Additionally, yield maps provide information on soil fertility and nutrient management by making it easier to calculate the rates at which nitrogen, phosphorous, and potassium are removed from the soil (Inman *et al.* 2005).

Field Mapping and Soil Sampling

The integration of GNSS with GIS has become indispensable in developing detailed agricultural field maps. These maps offer vital information about field variability, such as crop health, irrigation systems, drainage networks, soil types, and moisture levels (Moselhi *et al.* 2020). Targeted soil sampling is made possible by such comprehensive information, guaranteeing that soil tests are carried out at exactly designated sites.

By providing accurate location data, GNSS makes systematic soil sampling easier and guarantees that samples are regularly taken from the same spots over time. This repeatability improves soil analysis's dependability and yields a more precise evaluation of the nutrients and soil health (Radočaj *et al.* 2023).

Soil mapping has incorporated proximal and remote sensing technologies to further improve spatial resolution. While proximal sensing uses ground-based systems installed on cars or portable devices, frequently connected to GNSS receivers, remote sensing uses optical and radiometric sensors installed on satellites or aerial platforms (Pallottino *et al.* 2019).

In a vineyard field in southern Portugal, Serrano *et al.* (2023) mapped the soil's apparent electrical conductivity (ECa) using GNSS. Soil ECa was measured throughout the experimental field using the Veris 2000 XA contact-type sensor, which is outfitted with a GNSS antenna (Fig. 2). In order to establish management zones based on variables including soil texture, moisture content, pH, and electrical conductivity, the gathered data was examined. Rapid mapping of soil spatial variability has been demonstrated to be possible with GNSS-integrated mobile soil conductivity measurements.

In a different study, Triantakonstantis *et al.* (2021) mapped soil organic carbon (SOC) using GPS, remote sensing imaging, and GIS. GNSS technology was employed in the study to map SOC levels and take precise soil samples. In order to test soil characteristics, including SOC, sixty-seven soil samples were gathered. The results showed that accurate estimation models for important soil parameters like SOC may be produced by integrating GNSS with remote sensing technologies. The efficient management of agricultural ecosystems is greatly improved by the use of satellite data to evaluate soil characteristics.

Crop Monitoring and Management

The integration of GNSS with advanced technologies, such as remote sensing, enables continuous monitoring of crop conditions. This capability is critical for the early detection of crop stress,

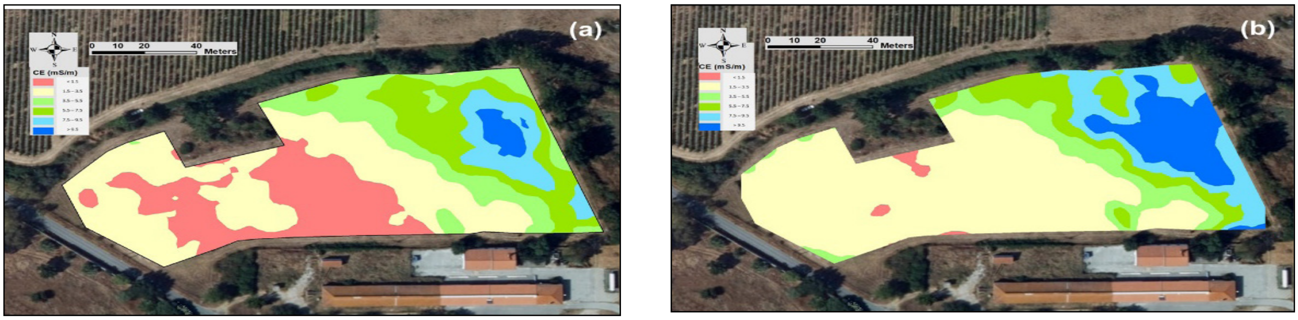

Fig. 2: Average soil apparent electrical conductivity (EC_a) maps of white grapes field in September **(a)** and October **(b)** 2022

diseases, and pest infestations. GNSS data ensures precision in intervention measures, reducing damage and enhancing yields by targeting specific areas for treatment.

GNSS technology plays a vital role in UAV-based aerial spraying systems by improving precision and safety. It reduces the possibility of spraying outside of approved zones, which lessens the impact on the environment and maximizes the use of available resources. In order to guarantee operational safety and effectiveness, GNSS also facilitates post-spraying analysis and evaluation (Biglia *et al.* 2022).

In a study by Kuchanwar *et al.* (2022), the spatial variability of soil parameters was examined using GNSS-based precision mapping. The accuracy of soil property maps was much improved by the integration of GNSS data with soil information, which made it easier to precisely regulate irrigation and nutrients.

Additionally, GNSS facilitates precise mapping and tracking of weed, bug, and pest infestations. In order to make well-informed input recommendations for future management decisions, infested regions within a field might be noted and mapped. Additionally, reliable seed placement, effective fertilizer application, and other field operations are guaranteed by the accurate guiding and automatic steering capabilities of GNSS systems. Increased yields, optimum input use, and better crop uniformity are the results of this accuracy (Fu *et al.* 2022).

GNSS positioning is used by map-based variable rate technology (VRT) systems to apply inputs, like fertilizer, herbicides, and irrigation water, at particular locations. Prescription maps can be created by combining GNSS data with yield maps, soil maps, and other geographical datasets. In order to maximize productivity and efficiency, these maps direct VRT equipment to apply inputs at varying rates suited to the unique requirements of various field zones (Rokhafrouz *et al.* 2021; Ammoniaci *et al.* 2021).

Irrigation Management

By providing precise water application based on precise field mapping and soil moisture measurement, GNSS technology has completely changed irrigation methods. By focusing water where it is most needed, this method reduces water waste and improves plant health.

A key GNSS-based technique for assessing soil moisture is GNSS Reflectometry. This method measures the delay and phase changes of GNSS signals reflected off the ground. The degree of delay and phase shift provides valuable insights into soil moisture levels, as wet soil reflects signals more effectively than dry soil. GNSS Reflectometry has demonstrated its potential for delivering accurate and reliable soil moisture measurements, enabling farmers to optimize irrigation and conserve water resources.

Soil moisture (SM) is a critical parameter in hydrological and agricultural studies, influencing flood detection, drought characterization, and irrigation planning. GNSS-based methods leverage L-band microwave signals, which are particularly sensitive to soil moisture. Recent advancements in GNSS Reflectometry (GNSS-R) and data analysis have enriched soil moisture monitoring capabilities. Compared with other remote sensing methods, GNSS-R offers unique advantages in terms of accuracy and practicality (Yang *et al*. 2024).

In addition to receiving signals from satellites, GNSS antennas also capture reflected signals from the ground, which contain environmental information. This process, known as GNSS-Interferometric Reflectometry (GNSS-IR), analyzes the signal-to-noise ratio (SNR) data to infer soil moisture levels. Changes in soil moisture alter soil permittivity and reflectivity, which in turn influence the SNR of the reflected signals. Experimental studies, such as those conducted by Chang *et al.* (2019) in Wuhan, China, have shown strong correlations between GNSS-estimated and actual soil moisture levels, with a root-mean-square error (RMSE) as low as 0.0345 cm^3/cm^3.

Several studies have further demonstrated the potential of GNSS multipath signals in retrieving geophysical parameters of the surface surrounding a GNSS antenna. For example, Motte *et al.* (2016) estimated soil moisture in wheat crops using SNR data derived from both direct and reflected GNSS signals. Similarly, Koch *et al.* (2016) employed geodetic GNSS antennas—one above the soil and two buried at a depth of 10 cm—to measure signal strength attenuation and retrieve soil moisture data over bare soil.

GNSS technologies not only improve irrigation scheduling but also enable farmers to develop data-driven strategies for efficient water management, ensuring sustainable agricultural practices.

Orchard and Vineyard Management

Precision agriculture (PA) in horticultural production has been significantly advanced by the integration of agricultural robots equipped with sensing, computation, and actuation capabilities (Sharifi and Chen, 2015). These robots enable efficient execution of operations such as precision spraying, pruning, and harvesting, addressing labor shortages and enhancing cost-effectiveness.

Autonomous navigation is a critical component of robotic operation in orchards. Precise path planning is essential to ensure robots can navigate effectively within orchard rows. Blok *et al.* employed particle filters and 2D LiDAR systems for robot localization in orchards. However, this approach is limited by low real-time performance and efficiency. To overcome these challenges, Guo Jing *et al.* (2018) introduced a multi-GNSS precise point localization method, improving the reliability and usability of robotic navigation under canopy-shaded conditions.

Peng *et al.* (2022) emphasized that the foundation of autonomous operations in orchards is a robust navigation system. Fig. 3 shows the machine model for orchard navigation and skeleton field map. Real-Time Kinematic Global Navigation Satellite System (RTK-GNSS) technology plays a pivotal role, offering centimetre-level positioning accuracy essential for effective field operations.

In vineyards, GNSS interferometry and reflectometry (GNSS-IR) techniques have proven valuable for monitoring environmental parameters. GNSS-IR has been widely used to assess soil moisture and snow depth (Larson *et al.* 2007). Additionally, GNSS-IR has demonstrated its potential in monitoring vineyard leaf moisture by analyzing the correlation between leaf moisture levels and GNSS signal-to-noise ratio (SNR) (Chew *et al.* 2015).

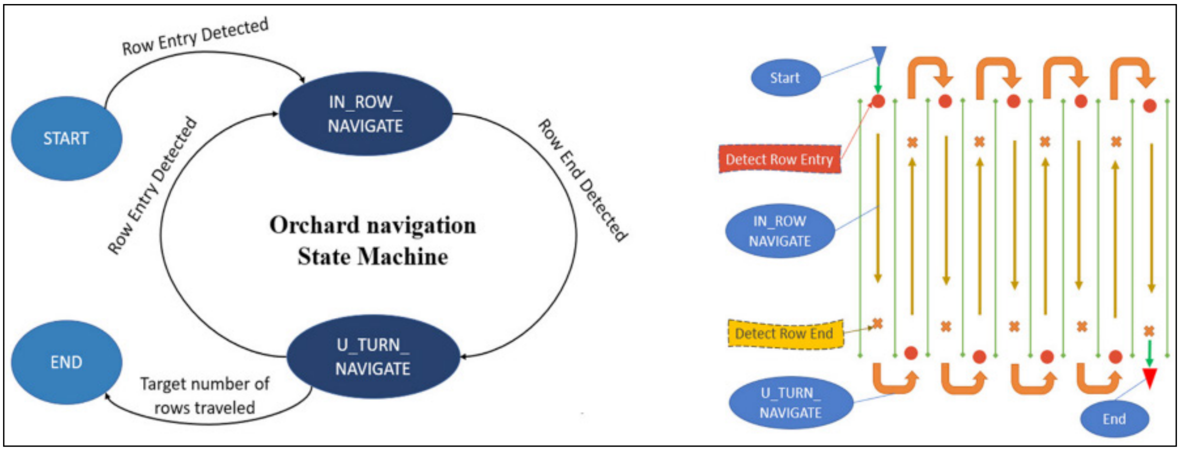

Fig. 3: Machine model for orchard navigation

The integration of GNSS technologies in orchard and vineyard management supports the development of advanced robotic systems and enhances decision-making processes, contributing to resource efficiency and sustainable horticultural practices.

Land Surveying and Planning

Global Navigation Satellite Systems (GNSS) have been an integral part of land surveying since the late 1980s, initially applied to geodetic control networks and photogrammetric control. Over time, advancements in GNSS technology, including enhanced compactness, improved usability, and the availability of satellites from multiple constellations, have significantly expanded its applications in surveying (Anonymous, 2023).

Modern GNSS systems are employed for a wide range of surveying and mapping tasks. These include establishing geodetic control points, setting out construction projects, monitoring real-time deformation, and providing on-board positioning for aerial surveys. As a positioning tool, GNSS uniquely offers a combination of precision, accuracy, efficiency, and cost-effectiveness (Upadhyaya *et al*., 2024).

The versatility and reliability of GNSS technology continue to drive innovation and adoption in surveying practices, ensuring that it remains a cornerstone of accurate and efficient land surveying and planning processes.

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