Soil Monitoring Market

Market Scenario and Competitive Landscape

A CURA DI

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Introduction and Methodology

“Market Scenario” is a customized and organized analysis to gather information about target markets and competitive landscape in a particular sector.

“Market Scenario” provides relevant information to identify and analyze market needs, market size and competition in the fields of interest of the customer. A technology or a product developed by the customer can be characterized according to the sectors and potentiality of application, target market, competitive advantages and potential partners of the technology. The analysis is performed with the application of technology and business intelligence tools. The research in the information providers is usually based on the use of keywords or by thematic area, according to the specific topic of interest.

The results of the assessment are data about the target or global market potential, market value and applicability of the technologies or products developed by the customer, the trends of the market of interest, the segmentation of the market (e.g., by application, geography or indication), the supply chain and the competitive advantages of products or technologies, the key players active in the market of interest and the possible direct or indirect competitors of the customer.

Context

This analysis reports data and trend about the **global soil monitoring market**, with reference to the main technologies, system types, the market by offering, by application and by region. The competitive landscape provides an overview of the main players active in the soil moisture monitoring market, with reference to the technologies applied.

1 Soil Monitoring

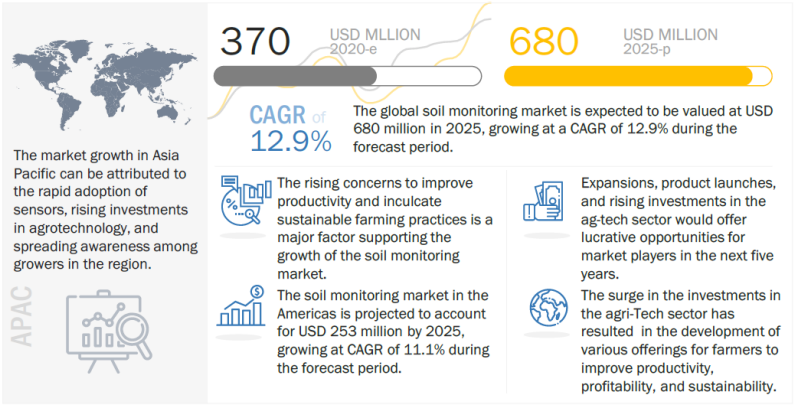
Soil monitoring is a practice that involves the use of various sensors, devices, and equipment, which makes use of advanced technologies for monitoring the soil to enhance soil productivity, farm profitability, sustainability, and the protection of the environment. Soil monitoring can be undertaken with the help of various systems such as ground-based monitoring systems which make use of soil sensors and handheld devices, sensing and imagery systems. These different systems enable growers and end users to provide site-specific inputs to farmers, thereby making agriculture practices more profitable and sustainable. Soil monitoring is utilized for both agricultural and non-agricultural applications. Non-agricultural applications mainly include soil monitoring in residential facilities, landscape and ground care, sports turf management, construction, and research studies.

A relevant number of **sensors** are used for monitoring and measuring various parameters such as nutrients, **moisture**, pH of the soil, and climate and provide real-time data to growers, agronomists, end users, and researchers, enabling them to take timely decisions.

1.1 Global Market and Market Dynamics

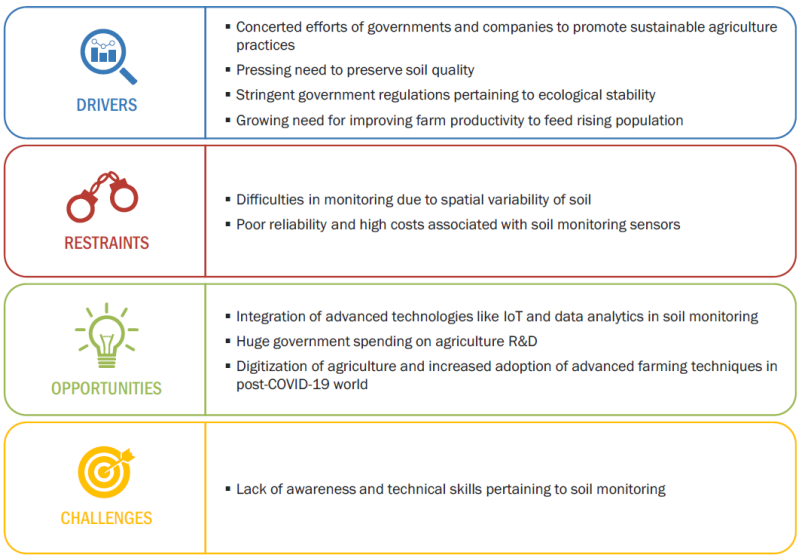
The soil monitoring market is at a **nascent stage** but reflects bright prospects. The use of various soil sensors has become more common in croplands due to innovations and reduced costs of sensors. Moreover, a number of companies are investing heavily in the ag-tech sector. The **global soil monitoring market** is expected to reach USD 680 million by 2025, growing at a Compound Annual Growth Rate (CAGR) of 12.9% during the forecast period (Figure 1).

Figure 1. Global Soil Monitoring Market, in the Period 2020 - 2025



The prominent factors **driving** the growth of the soil monitoring market are the rising efforts to encourage the adoption of sustainable agriculture practices, rising concerns regarding deteriorating soil quality, stringent government regulation pertaining to ecological stability, and the pressing need to improve farm productivity to cater to the burgeoning global population (Figure 2). The adoption of various soil monitoring systems such as ground-based soil monitoring systems, sensing and imagery systems, and telematics and robotics is increasing worldwide. Conversely, issues related to the spatial variability of soil, which make soil monitoring difficult, and low reliability and high costs of soil monitoring sensors are some of the factors **inhibiting** the growth of the market.

Figure 2. Market Dynamics for Soil Monitoring Market



1.1.1 Technology analysis

Soil sensor technologies

The soil monitoring market has been consistently evolving over the past few years owing to advancements in various **technologies**, such as remote soil monitoring, remote soil testing, inclusion of IoT in soil monitoring, along with data visualization using software and other platforms. Hardware devices and components such as **soil monitoring sensors**, probes, data loggers, network devices, and weather stations play a crucial role in analyzing various metrics associated

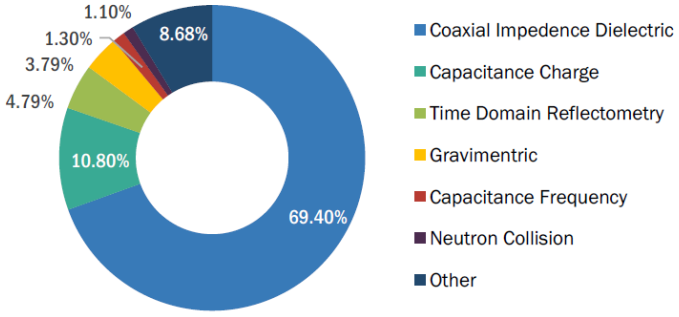
with soil. **Soil moisture** monitoring plays an important role in agricultural as well as in non-agricultural applications as several activities, such as irrigation and construction, are dependent upon the moisture content in soil. Several **technologies** are used for the measurement of the volumetric water content of soil using commercial soil sensors (Table 1).

Table 1. Soil Sensor Technologies for Soil Monitoring

Technology	Operating Principal	Physical Measurement	Basis for Soil Moisture	Typical Frequency
Time Domain Reflectometry	Sensors based on this technology measure the time required by an electromagnetic wave to travel out and be reflected back from the end of the probe.	Time for voltage pulse to travel along parallel rods and reflect back	Apparent permittivity	1000 MHz
Time Domain Transmissometry	Devices based on this technology measure the time taken by an electromagnetic wave to travel in one direction over the length of the probe	Time required for a voltage pulse to travel the length of looped of closed-circuit rod	Apparent permittivity	150 MHz
Capacitance (Frequency)/Frequency Domain Reflectometry	This technology measures the difference in the frequency of an electromagnetic wave traveling out and being reflected back to the sensor head	Change in the output wave and return wave frequency	Capacitance	N/A
Capacitance (Charge)	This technology measures the charge time of a capacitor that uses the medium surroundings of the probe as a dielectric material	Capacitor charge time	Capacitance	N/A
Differential Amplitude (Simplified Impedance)	This technology measures the change in the incident signal and the reflected signal to determine impedance and apparent permittivity	Change in reflected amplitudes	Apparent permittivity	75 MHz
Coaxial Impedance Dielectric Reflectometry	This technology measures the ratio of reflected voltage to an incident voltage of a 50 MHz signal, which is dependent on the impedance of the medium between the probe rods	Ratio of reflected amplitudes to measure the impedance	Real dielectric permittivity	50 MHz
Neutron Collision	This technology is based on measuring fast-moving neutrons that are slowed down by an elastic collision with existing hydrogen particles in the soil	Collision of emitted neutrons with hydrogen atoms	Apparent permittivity	N/A
Gravimetric Soil Analysis	The gravimetric water content is measured by weighing soil sample, drying the sample to remove the water and then weighing the dried soil	Change in the soil weight before and after being dried to remove all water	Mass of water	N/A

The adoption of the main technologies for soil sensing in 2019 is reported in the following figure. **Neutron collision** technology is considered among the minor techniques applied in 2019 (1.10%).

Figure 3. Soil Sensor Technologies Adoption in 2019

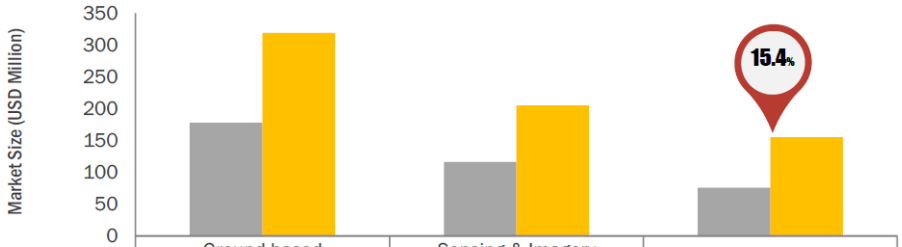


1.2 Market by System Type

Based on **system type**, the soil monitoring market has been segmented into **sensing and imagery systems**, **ground-based sensing systems**, and **others** (include telematics and robotics, which is at a nascent stage of adoption among growers). The **ground-based monitoring systems** segment is expected to showcase noteworthy growth during the forecast period. Ground-based monitoring is the most common type of system used for soil monitoring in agricultural and non-agricultural applications. The use of sensors, equipment, and handheld devices is more prominent for soil monitoring as compared to other system types. Ground-based monitoring systems can be availed at low costs and offer flexibility in the choice of sensor. Widespread adoption of sensors for agricultural and non-agricultural applications has led to the larger market share of ground-based sensing systems.

The **sensing and imagery systems** segment is expected to reach the value of USD 205 million by 2025, growing at a CAGR of 12.1% in the period 2020 – 2025. The **other** system types, which includes robotic and telemetry, is expected to witness high growth during the forecast period. The major factor supporting the growth of the segment is the advent of connected farming. A number of agriculture technology companies exist in the market that provide integrated solutions to monitor fields.

Figure 4. Soil Monitoring Market by System Type, in the Period 2020 - 2025



	Ground-based Monitoring Systems	Sensing & Imagery Systems	Others
2020	178	116	76
2025	319	205	155
CAGR (2020-2025)	12.3%	12.1%	15.4%

Others include robotic and telematics systems.

1.2.1 Ground-Based Monitoring Systems

Ground-based monitoring makes use of various standalone systems, devices, sensors, scanners to measure various metrics of the soil, such as moisture, pH, nutrient,

temperature, and salinity. Ground-based monitoring uses nutrient sensors, **moisture sensors**, salinity sensors, temperature sensors, probes, soil scanners, and other handheld devices to gather soil or field-level information. These sensors or devices could be wired or wireless and are used by operators while moving in fields or are installed in the field. Ground-based monitoring helps to establish a connected environment and provides real-time information to growers or end users on their laptops, PCs, or smartphones.

Handheld devices are used in various applications, such as yield monitoring, soil monitoring, and mapping. Unlike satellite remote sensing, ground-based monitoring does not require strong technical know-how for operation, and thus is popular among farmers. Another reason for the popularity of ground-based monitoring is the availability of application-specific sensors that could be bought separately by farmers.

Non-agricultural applications of ground-based monitoring include the use of sensors and soil monitoring devices for landscape and ground care, sports turf management, weather forecasting and drought management, and several research studies. Ground-based monitoring systems are widely used in construction and mining industries where the soil water content, compaction, and topography play a vital role.

The major players providing **ground-based monitoring systems** in the soil monitoring market are Stevens Water Monitoring System (US), The Toro Company (US), Campbell Scientific (US), Delta-T Devices (UK), Meter Group (US), and Sentek Technologies (Australia).

1.2.2 Sensing and Imagery Systems

Sensing and imagery systems have further been segmented into: satellite-based soil monitoring, manned aircraft/aerial photography-based soil monitoring, and drone-based soil monitoring.

Sensing and imagery systems use **remote sensing technology** along with various hyperspectral and multispectral sensors for imaging. Remote sensing technology aids growers to monitor their field soil from a distant place in real time and to get data pertaining to the field on data visualization platforms. Remote sensing technology could also be used to obtain various spatial layers of information about soil and crop conditions. The use of satellite imagery, drones, manned aircraft, or aerial imagery is more prominent in agricultural applications of soil monitoring where these imaging systems gather raw data pertaining to soil.

Further data about Sensing and Imagery Systems and about the market segment related to Telematics and Robotics are available on request.

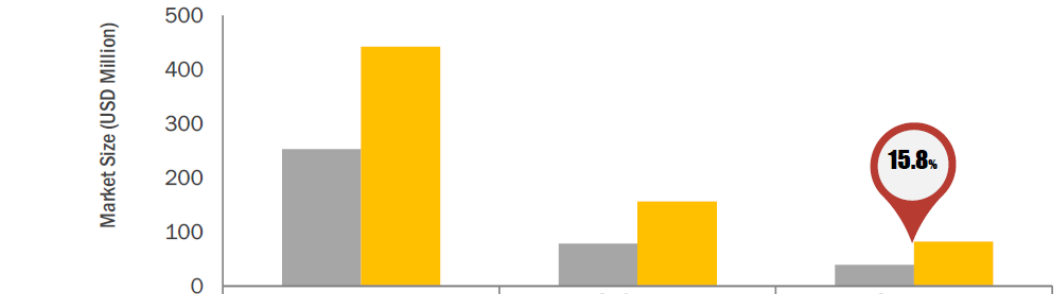
1.3 Market by Offering

The soil monitoring market, based on offering, has been segmented into: **hardware, software, and services**. The hardware segment has been further classified into camera systems, **sensors**, telematics, soil testing devices, and others. The **hardware** segment held the largest share of the soil monitoring market in the year 2019, and a similar trend is expected to be observed from 2020 to 2025. Also, the market for this segment is likely to grow at a significant rate during the forecast period. The integration of varieties of sensors into remote monitoring solutions owing to the reduced cost of these sensors has resulted in the largest market share of the hardware segment.

The **services** segment is expected to witness the highest growth rate in the soil monitoring market during the forecast period. The advent of connected farming, the utilization of IoT in agricultural and non-agricultural applications, and the availability of new revenue generation models offered by agriculture technology companies have led to an increase in demand for services in the soil monitoring market.

Software solutions are used to interpret and analyze the gathered data and form a visual representation of that information. The software could be local, i.e., on-premises, or it could be cloud-based. Cloud-based solutions are further classified into 2 categories: software as a service (SaaS) and platform as a service (PaaS). The software segment also includes AI and data analytics, as well as farm management software. The service offerings in the soil monitoring market include system integration and consulting, managed services, connectivity services, and assisted professional services.

Figure 5. Soil Monitoring Market by Offering, in the Period 2020 - 2025



	Hardware	Software	Services
2020	253	78	39
2025	442	156	82
CAGR (2020–2025)	11.8%	15.0%	15.8%

1.3.1 Hardware

The **hardware** segment in the soil monitoring market includes various types of **sensors**, such as **soil moisture sensors**, soil nutrient sensors, pH sensors, salinity sensors, and temperature sensors. The hardware segment also includes smart imaging systems, data loggers and telemetry systems, portable soil scanners, and others (weather stations, water flow meters, network devices and components).

Table 2. Soil Monitoring Market for Hardware, by Offering, 2020–2025 (USD Million)

Hardware	2020	2021	2022	2023	2024	2025	CAGR (2020–2025)
Sensors	173	186	206	230	259	292	11.1%
Smart Imaging Systems	20	23	26	31	37	44	17.6%
Data Loggers and Telemetry Systems	33	36	41	47	54	62	13.7%
Portable Soil Scanners	9	10	11	13	15	18	15.2%
Others*	19	20	21	23	25	27	6.4%
Total	253	274	305	343	389	442	11.8%

**Others include network devices and components, water flow meters, and weather stations*

Sensors

Different types of sensors deployed in soil monitoring systems are **soil moisture sensors**, nutrient sensors, pH sensors, temperature sensors, salinity sensors, and climate sensors. Volumetric soil moisture sensors and soil water potential sensors are the two key types of soil moisture sensors. **Volumetric soil moisture sensors** include probes, capacitance sensors, and time-domain transsiometry sensors. Soil water potential sensors include tensiometers, gypsum blocks, and granular matrix sensors. These sensors provide information related to various parameters of the field in real-time and assist in better decision-making. Moreover, advancements in sensor technology, along with the reducing cost of sensors, have resulted in their increased adoption by growers to reduce their cultivation cost and earn better returns.

Table 3. Soil Monitoring Market for Sensors, by Type, 2020–2025 (USD Million)

Sensor Type	2020	2021	2022	2023	2024	2025	CAGR (2020–2025)
Volumetric Soil Moisture Sensors	69	74	83	93	105	119	11.3%
Soil Water Potential Sensors	26	29	33	38	44	51	14.4%
Others*	77	83	90	99	110	122	9.6%
Total	173	186	206	230	259	292	11.1%

**Others include temperature sensors, pH sensors, nutrient sensors, climate sensors, salinity sensors*

Other sensor types such as temperature sensors, pH sensors, climate sensors, and salinity sensors are being adopted on a large scale for agricultural and non-agricultural applications. These sensors are in demand for measuring a wide variety of soil parameters in agricultural and non-agricultural applications. Soil water potential sensors are expected to record the highest CAGR during the forecast period owing to their high efficiency to determine the moisture level in the soil. Moreover, soil water potential sensors have been used vividly in non-agricultural applications to control soil erosion, as well as for drought and flood management.

Volumetric Soil Moisture Sensors

Volumetric soil moisture sensors measure the actual amount of water in the soil by calculating the driving force for water movement through it. This method of monitoring soil moisture directly states the availability of soil water to the roots. Measurements taken by these sensors are independent of the soil type and bulk density. However, site-specific experience or the proper knowledge regarding the appropriate use of dynamic protocols is required for interpreting the information obtained through the readings taken by these sensors for regular irrigation management.

A volumetric sensor is generally available in the form of a **probe**, which is the most accurate tool used for measuring soil moisture. Probes are generally rods made up of steel or fiberglass with an average length of ~5–10 cm. Sensors can be buried under the soil at the desired depth, while probes can be directly inserted into the soil. Probes can be installed in 2 ways, depending on their structure. A flat probe is installed horizontally, whereas a node probe is installed vertically in the ground. Different variants of probes, such as electrical conductivity probes, coaxial impedance dielectric reflectometry probes, and neutron probes, based on the type of source of emission, are available in the market. Although volumetric sensors provide more accurate data and require less calibration compared to soil water potential sensors, the determination of irrigation time is not an easy task with these sensors.

Volumetric soil moisture sensors are mainly used for the research purpose owing to their ability to provide highly accurate data. Various types of volumetric soil moisture sensors, such as **neutron probes** and dielectric sensors, including time-domain transmissiometry (TDT) sensors and capacitance sensors, are available in the market. TDT sensors are also known as time-domain reflectometry (TDR) sensors, while capacitive sensors are also known as frequency-domain reflectometry (FDR) sensors.

Table 4. Soil Monitoring Market for Volumetric Soil Moisture Sensors, by Type, 2020–2025 (USD Million)

Type	2020	2021	2022	2023	2024	2025	CAGR (2020–2025)
TDT Sensors	34	36	39	43	48	53	9.5%
Capacitance Sensors	28	30	34	38	44	50	12.5%
Neutron Probes	8	9	10	11	13	15	14.4%
Total	69	74	83	93	105	119	11.3%

Neutron probes provide the most accurate data, and these are widely adopted in soil moisture monitoring. Neutron probe is a time-tested method for measuring the water content in a given volume of soil by measuring the amount of hydrogen present in it. The neutron probe is made up of polyvinyl chloride (PVC) or aluminum tube with an encased neutron source at its one end. To take the measurement, the probe is inserted vertically in the soil to the desired depth. The source emits low-level radiation in the form of neutrons; neutrons are then collected and counted by the helium-3 detector when they get reflected after colliding with the hydrogen atoms present in water. The working of these probes is based on the fact that the more the water content in the soil, the more neutrons are scattered back at the probe.

Neutron probes have several advantages over other types of sensors as they provide the most accurate readings when calibrated properly; therefore, these probes are highly reliable as the measurement is not affected by small air gaps, temperature, or salinity. These probes are easy to install and relatively permanent as they can be used several times. Another advantage is that they capture readings for a spherical area of about 30 cm diameter and a depth of more than 80 cm (however, depth shallower than 20 cm is normally not recommended), which is relatively greater than any other method.

High costs of probes and stringent regulations pertaining to the adoption of neutron probes are limiting the use of neutron probes. The presence of a radioactive source mandates the involvement of properly trained and licensed operators for its handling, storage, and use; therefore, it is not used directly for controlling the irrigation system. Apart from this, probes require calibration for each soil type, and near-surface readings are less accurate as emitted neutrons escape at a fast rate from the top layer. **InstroTek** (US) and **Troxler Electronic Laboratories** (US) are manufacturers of neutron probes.

A **capacitance sensor** is an alternative tool for calculating the volumetric content of the soil moisture; this tool is based on the concept of dielectricity. Capacitance sensors are widely used in research studies and agricultural applications. These sensors are available in various configurations, from a pair of parallel pronged probes to parallel pairs of rings along with a probe or a rod. The ability to take direct readings, no requirement for special maintenance, and a wide operating range are the benefits associated with capacitance sensors. Capacitance sensors also provide accurate data; however, proper contact with the soil is a must to maintain accuracy by avoiding any air gaps. It is necessary to calibrate these sensors after every installation since the soil moisture threshold varies with the soil texture. Major **players** involved in the manufacturing of **capacitance sensors** are METER Group (US), Sentek (Australia), Delta-T Devices (UK), Spectrum Technologies (US), CropX (Israel), Caipos (Austria), AquaSpy (US), and AquaCheck (South Africa).

TDT is one of the two dielectric methods used for calculating the volumetric soil moisture content, an upgraded version of TDR sensors. TDT sensors are also known as electrical conductivity probes, and their working is based on the principle of electrical conductivity between the 2 probes. The water content of the soil is calculated by measuring the time taken by the pulse to travel back to the probe. These probes are generally flat and are buried horizontally inside the ground at a certain depth. The length of the rods varies from 8 to 100 cm, depending on the application. These probes have direct contact with the soil as they are not shielded with any outer layer. Another variation of the TDT sensor is available in the

form of the coaxial impedance dielectric **reflectometry probe**, a standing wave sensor that usually consists of a body and head. These probes take measurements by generating an electromagnetic signal with the help of an oscillator that propagates through the metal spikes into the soil.

Key benefits of TDT sensors are as follows: these probes can be used multiple times; a single probe can be used to take readings at multiple depths; they are available for direct measurements; and they require less maintenance. Major **players** involved in the manufacturing of **TDT sensors** are Campbell Scientific (US), Spectrum Technologies (US), Mesa Systems (US), Van Walt Systems (UK), Acclima (US), Baseline (US), IMKO Micromodultechnik (Germany), E.S.I. Environmental Sensors (Canada), and Streat Instruments (New Zealand).

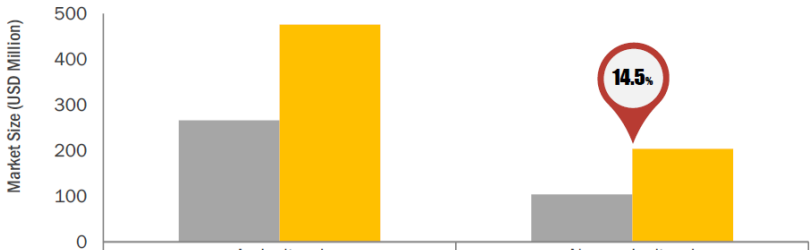
Other market data related to the software and services segments are available on request

1.4 Market by Application

By application, the soil monitoring market has been segmented into 2 primary applications: **agriculture** and **non-agricultural applications**. The agriculture application has been further segmented into: field crops (open field farming and row crops), smart greenhouse, vertical farms, and others (orchards, and cannabis/hemp). The non-agricultural application includes residential, landscape, ground care, sports turf, forestry, construction and mining, weather forecasting, and others (gardening, research and agriculture labs, water reservoir, and drought management). The market for the **agricultural application** is expected to reach USD 476 million by 2025, at a CAGR of 12.3% from 2020 to 2025. Agriculture is the primary application of soil monitoring devices, sensors, components, and equipment. The use of soil sensors in agriculture leads to the optimization of various inputs usage, increase in product yield, production of high-quality crops, and reduction in environmental degradation occurring through resource depletion.

However, the **non-agricultural application segment** is on an upward growth trajectory owing to the adoption of various portable devices and imaging systems for soil monitoring purposes, especially for weather forecasting and flood and drought management.

Figure 6. Soil Monitoring Market by Application, in the Period 2020 - 2025



	Agricultural	Non-agricultural
2020	266	104
2025	476	204
CAGR (2020-2025)	12.3%	14.5%

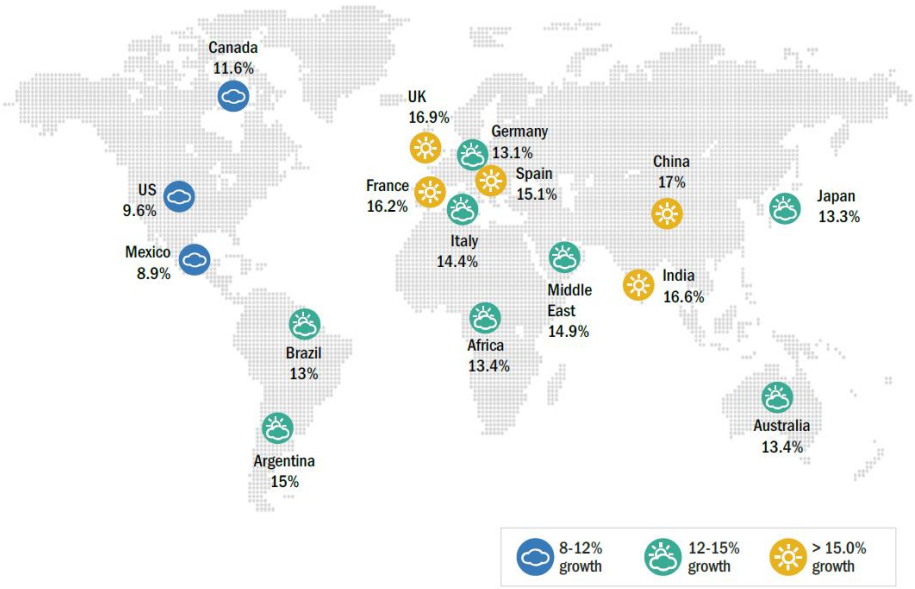
1.5 Market by Region

The market in the **Americas** is expected to reach USD 253 million by 2025, at a CAGR of 11.1% during the forecast period. The Americas market segment is expected to account for the largest share of the soil monitoring market owing to the presence of major market players such as Meter Group (US), Stevens Water Monitoring System (US), The Toro Company (US) and Campbell Scientific (US). Further, countries in this region, such as the US and Canada, are the early adopters of sensing and imagery, telematics, automation, and robotics.

Europe is likely to hold the second-largest share of the soil monitoring market in 2020. This market segment is expected to reach the value of USD 211 million by 2025, growing at a CAGR of 13.9%. The market in Europe is projected to witness substantial growth in the coming years as this region is an early adopter of drone-based sensing, telematics, and robotics and automation system in farms owing to labor scarcity and the need to become self-sufficient in terms of agricultural production.

Asia Pacific (APAC) is likely to witness a tremendous growth with a CAGR of 14.6% during the forecast period. The increasing demand for advanced sensors in major agrarian economies in APAC, such as Australia, China, and India, has led to the widespread growth of the soil monitoring market in APAC. Moreover, rising internet penetration supporting the connected farming ecosystem has contributed to the development of digital farming infrastructure in the region, thereby accelerating the growth of the soil monitoring market.

Figure 7. Global Soil Monitoring Market in the Period 2020 - 2025

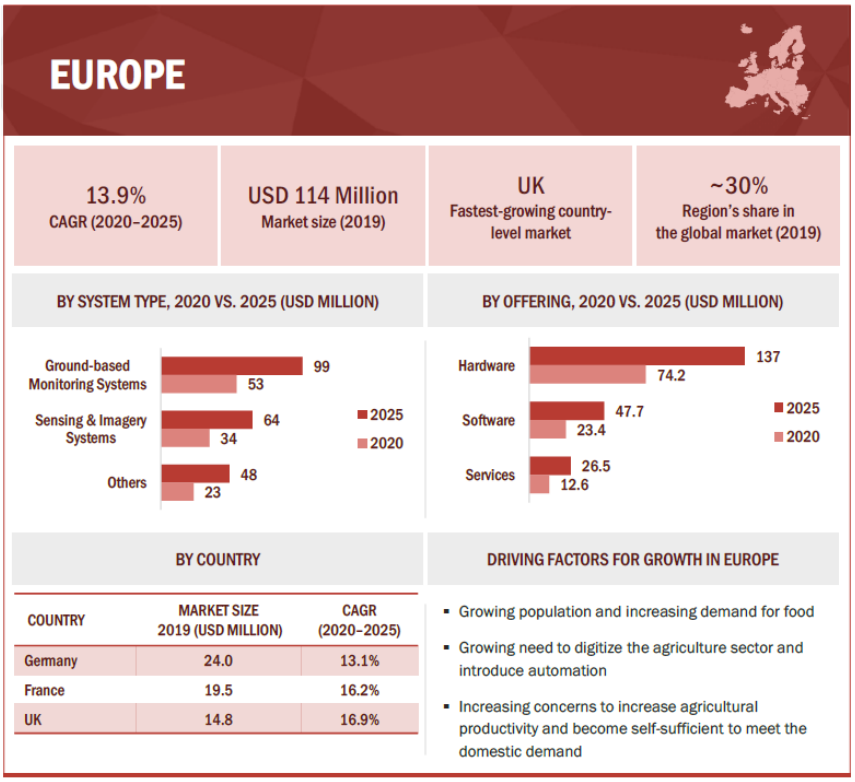


1.5.1 Focus on Europe

The market in **Europe** is further segmented into: France, Germany, the UK, Italy, Spain, Poland, and Rest of Europe, which mainly includes Netherlands, Denmark, and Finland. These countries are expected to continue to be the major drivers of the European soil monitoring market in the coming years. The use of digital farming techniques has become more prominent in Europe owing to advancements in the field of sensors, robotics and automation, and remote sensing technology. At present, the adoption potential for soil monitoring sensors, equipment, and devices in Europe is high. European countries are deploying soil sensors in advanced agriculture techniques such as precision farming and yield monitoring.

Europe is home to some of the advanced countries utilizing agriculture technology, with a number of startups catering to the agriculture ecosystem. Countries such as **Germany**, France, Netherlands, and the UK are some of the major countries in terms of technology adoption in the agriculture sector. The European market for ground-based monitoring systems held the largest market in terms of value (USD 53 million) in 2020 (Figure 8).

Figure 8. Snapshot: Soil Monitoring Market in Europe



Germany

Germany is one of the pioneer countries in the development of precision farming-related services, which include various equipment and farm data management systems. The German government provides funding for bringing developments in precision farming techniques; for instance, the country received funds worth ~USD 28.8 million during 1995–2005 from the German research and education ministry.

Germany has been an early adopter of various new technologies, and soil monitoring is expected to provide it with increased productivity for its agricultural applications. Sensors are also expected to provide users with the effective management of critical water resources in water consuming applications, such as sports turfs, residential irrigation, landscaping, and ground care. Germany has also been at the forefront in R&D, and the application of sensors in this field is also expected to contribute to the growth of the market in this country. **IMKO Micromodultechnik** (Germany), one of the leading providers of soil sensors for various applications, is headquartered in this region.

Italy

Italy is the third-largest economy in the eurozone with a GDP of USD 2.3 trillion, and agriculture is one of the key economic sectors, accounting for 1.4% of the GDP. According to the World Bank, agricultural land in Italy held 45.8% in 2016, and farms in Italy are mostly small, with an average size of 11 hectares. The country is a net agriculture importer as Italy's strength lies in processing and manufacturing goods. Italy is among the top producers of corn in the EU. In 2017, according to the EuroStat crop statistics, Italy produced more than 7 million tons of corn in an area of 700,000 hectares.

Precision farming technology in Italy is relatively underdeveloped compared to the UK or Germany. Farms in Italy are moving toward advanced digital farming techniques to compensate for their earlier losses. Precision farming practices are becoming popular and are used for managing irrigation performance, improving yield, and reducing fertilizer cost, as well as for optimum resource management. Companies in Italy are becoming aware of the benefits of digital agriculture and are increasingly using digital solutions through the use of machinery or advanced technology for crop monitoring, seeding, cultivation and harvesting. TeamDev, XFarm, and Omica are among the few Italian companies to be inspired by digital farming solutions. Omica, an Italian start-up, collaborated with Libelium to get an IoT-based wireless sensor network in practice.

1.6 Competitive Landscape

The **top 5 players** in the soil monitoring market are: Element Material Technology (UK), Meter Group (US), SGS Group (Switzerland), Stevens Water Monitoring System (US) and The Toro Company (US). **Other key players** include Campbell Scientific (US), CropX Technologies (Israel), Delta-T Devices (UK), Irrometer (US), Sentek Technologies (Australia), Spectrum Technologies (US) and Trimble (US).

For the identification of the global players active in the development of soil moisture probes or sensors, a targeted company search has been conducted among the sources Markets&Markets and Lux Research. The majority of the players identified develop soil moisture monitoring technologies based on **TDR** or **capacitance** technologies. In order to provide a complete description of the market scenario, these players have been reported in the following table.

Table 5. Companies Active in the Soil Moisture Monitoring Market

Company	Geography	Description	Technology	Website
Acclima	USA	Acclima is a manufacturer of precise and stable soil moisture sensors used in research and irrigation control systems. It provides patented digital TDT and digital TDR soil moisture sensors	TDT, TDR	https://acclima.com/
AquaCheck	South Africa	AquaCheck is a manufacturer of capacitance-based soil moisture probes. It also provides an online soil moisture management software platform that hosts, processes, and displays soil moisture and related data online	Capacitance	https://aquacheck.co.za/
AquaSpy	USA	AquaSpy develops soil moisture sensors to measure and monitor soil moisture levels. The company deploys underground sensors that collect soil moisture data, which is transmitted to farmers through personal computers and mobile devices	Capacitance	https://aquaspy.com/
Baseline (Hydropoint)	USA	The company develops, manufactures, and markets patented soil moisture sensors along with two-wire technologies, intelligent irrigation controllers, and powerful central and remote-control platforms	TDT	https://www.hydropoint.com/baseline/
Caipos	Austria	In the soil monitoring market, the company provides wireless monitoring of soil moisture and climate, irrigation control monitoring, and C-Kit (mobile soil moisture measurement device)	FDR capacitive sensor	https://www.caipos.com/

Campbell Scientific	USA	The company provides a wide range of sensors for the measurement of environmental and water resource parameters. It offers soil volumetric water content sensors, soil heat flux sensors, soil temperature sensors, soil conductivity sensors, and soil water potential sensors	TDR	https://www.campbellsci.com/
E.S.I. Environmental Sensors	Canada	E.S.I. Environmental Sensors is engaged in the development, manufacture, sale, and after-sale servicing of environmental sensors and water content measurement instrumentation and related technology for a variety of applications	TDT, patented TDT5 technology	https://www.esica.com/
IIMKO Micromodultechnik	Germany	The company offers water content, material moisture, and environmental monitoring instruments for various applications through its patented TRIME and ENVIS technologies	TDR	https://www.imko.de/en/
METER Group	USA	The products offered through the METER Environment segment include soil moisture/water content sensors, soil water potential sensors, data loggers, weather monitoring stations and other accessories for monitoring and sensing applications	Capacitance	https://www.metergroup.com/
Plantcare	Switzerland	The company develops soil moisture sensors and smart irrigation controllers for agriculture	Micro-thermal measurement	https://www.plant-care.ch/english-1/
Sensoterra	The Netherlands	The company develops wireless soil moisture sensors	Patented: Impedance (soil resistivity and capacitance)	https://www.sensoterra.com/
Sentek Technologies	Australia	Sentek Technologies is one of the leading providers of sensors and advanced software. It manufactures and sells sensors and solutions for precision measurement and soil water and salinity dynamics management	Capacitance	https://sentektechnologies.com/
Spectrum Technologies	USA	Spectrum Technologies is one of the renowned players in the soil monitoring market with several offerings for weather monitoring, nutrient management, soil and water monitoring, plant health for agriculture, and sports turfs segments	TDR, Capacitance-type	https://www.specmeters.com/
Stevens Water Monitoring Systems	USA	The company is a leader in soil monitoring instrumentation and offers portable and in-situ sensors to measure various parameters, such as soil moisture. HydraProbe, HydraGo, and HydraGo Field Version are the key sensor products offered by the company	“Dielectric impedance” measurement	https://stevenswater.com/
Vegetronix	USA	Vegetronix specializes in innovative agricultural electronic systems, which include low-cost soil moisture sensor probe. The company provides VH400 series of soil moisture sensor probes and VG-METER-200 digital soil moisture meters	TDR	https://www.vegetronix.com/

As reported in the source Markets&Markets, **InstroTek** (US) and **Troxler Electronic Laboratories** (US) are considered among the major manufacturers of **neutron probes**. These players are not further described in the source consulted. For this reason, below is provided a quick overview of the two players, according to their corporation websites:

- InstroTek is a global leader in products and technology development for the construction and raw materials industry, developing the world's first portable nuclear gauge calibration device. The in-depth knowledge of nuclear and non-nuclear instrumentation enables the Company to address some of the most complicated measurement problems. InstroTek produces the 503 ELITE Hydroprobe, a subsurface, accurate neutron probe designed to measure soil moisture. The main applications of the probe are in irrigation scheduling, agronomic research, and environmental monitoring;
- Troxler Electronic Laboratories is an electronic manufacturing company providing control and measurement equipment. Troxler pioneered the development and production of the nuclear testing and measuring devices used in construction and agricultural industries.

According to the source Lux Research, only the company **Silverside Detectors** (USA) develops Li-6 neutron detectors based on **Cosmic Ray Sensing** for soil moisture monitoring applications. Lux Research reports that the company has developed prototypes and lab-scale production facilities but does not yet have full scale production facility. As reported by Lux Research, the **direct competitors of Silverside Detectors** include:

- John Caunt (UK): produces hand-held and installed radiation monitoring systems, scintillation detectors and a comprehensive range of standard and novel radiation shielding products, including neutron monitors;
- Ludlum Measurement (USA): designs and manufactures radiation detection instruments and technologies. Their instruments are used in applications such as routine personnel and material monitoring, border security, and emergency response situations;
- Ortec (UK): designs and manufactures ionizing radiation detectors, nuclear instrumentation, analysis software, and integrated systems.

For these players, **no specific references to soil moisture monitoring technologies** have been found.

Moreover, several players are present in the radiation monitoring space; most of them rely on helium-3 or barium technology. Other players active in the radiation or neutron detection field are involved in the development of solutions for nuclear, radiation or radon monitoring or for medical applications, and for that reason not included in this search (e.g., **Quaesta Instruments**, mapped by Lux research and by the patent intelligence analysis).

2 Conclusions

Soil monitoring involves the measurement of various soil properties, such as **moisture** content, salinity, temperature, pH level, and nutrients, to optimize farming processes by providing site specific inputs. The use of **sensors** in soil monitoring has become commonplace as sensors are used to determine the various parameters of the soil, such as soil temperature, moisture content, salinity, pH, and nutrient level. The **global soil monitoring market** is expected to reach USD 680 million by 2025, growing at a CAGR of 12.9% during the forecast period 2020 – 2025.

Volumetric soil moisture sensors are mainly used for the research purpose owing to their ability to provide highly accurate data. Various types of volumetric soil moisture technologies, such as **neutron probes** and dielectric sensors, including time-domain transmissiometry (TDT) sensors and capacitance sensors, are available in the market. **Neutron probes market segment** is expected to reach the value of USD 15 million by 2025, growing at a CAGR of 14.4% in the period 2020 – 2025.

Cosmic Ray Neutron Sensor (CRNS) technology is a promising method for the measurement of water content in the soil in an efficient and non-invasive way. Different small players/startups are currently developing cosmic ray neutron probes/sensors. However, these players have been primarily mapped by bibliographic searches and free access sources.

In this analysis has been identified only one player developing CRNS technology: **Silverside Detectors**, and **no market data** have been found about this specific technology.

Probably, the few data available about CRNS technology are related to the fact that the developers of this method are mainly small players or startups, and that the products are still in the development or prototype phase, and for these reasons still not mapped or included in the global soil monitoring market. Moreover, several barriers (technological, economic or regulatory) could limit the adoption of this technology in the market.

3 Sources

MarketsandMarkets Knowledge Store - Multisectoral database that collects market research reports in various technological fields and designed to process some information interactively. More than 1,200 market reports are published each year (https://www.mnmks.com/)[1]. The information presented are contained in the Report "Soil Monitoring Market – Global Forecast to 2025", September 2020.

Lux Research - Lux is a research and advisory firm, focused on sustainable innovation that is commercially viable. Lux's diverse team of analysts work cross-functionally across industries as well as technologies, using proprietary research methodologies to unlock unique insights (https://www.luxresearchinc.com/). The provider has been used to identify companies active in the development of soil moisture monitoring systems and neutron detection technologies.

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