Identification of Technical Practices for Climate-Smart Agriculture (CSA) in Indonesia: A Case Study in the Sukabumi Regency, West Java

Output 2 – Identify Technologies to Support the Identification of Water Content and Soil Chemistry on Agricultural Land

Technology Fact Sheets (D2.1.2)

Document Information

Project No.	62802781		
Project Title	Identification of Technical Practices for Climate-Smart Agriculture (CSA) in Indonesia: A Case Study in the Sukabumi Regency, West Java		
Subject	Output 2 – Technology Fact Sheets (D2.1.2)		
Document No.	62802781-TNT-403	**Rev**	01

Current Revision Approvals

	Name / Title	Date
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Document Revision History

Rev	Rev Date	Description of Change/ Reason for Issue	Prepared by	Checked by	Approved by
01	Jun 26, 2023	Final	SKS, AFF, SFF, AH	MABE	SMH

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1 Introduction

This document aims to provide an overview of the different soil sensing technologies available on the market, summarising their main characteristics, functions, advantages, and disadvantages. Soil sensing technologies are used to measure various soil properties, such as moisture, temperature, salinity, and nutrient content. These measurements can be used to improve climate-smart agricultural practices, manage environmental resources, and assess the impact of climate change.

There are four main categories of soil sensing technologies presented in this document:

- Field-implanted sensors **(Section 2)** are placed directly in the soil to measure soil properties. These sensors can provide high-resolution data but can be challenging to install.

- Remote sensing satellites **(Section 3)** collect soil data from space. These sensors can provide large-scale data but may not be as accurate as data collected from field-implanted sensors or UAVs.

- Unmanned aerial vehicle (UAV)-based sensors **(Section 4)** are mounted on drones or other small aircraft to collect soil data from above. These sensors can collect data over a limited area.

- Combination technological systems **(Section 5)** combine data from multiple sensors to provide a more comprehensive view of soil conditions. These systems can be the most expensive, but they can also provide the most accurate data.

The choice of soil sensing technology depends on the specific needs of the user. For example, farmers may need to use field-implanted sensors to monitor soil moisture levels in their fields, while environmental scientists may need to use remote sensing satellites to collect data on soil erosion over a large area.

This catalogue helps users choose the suitable soil sensing technology for their needs. It provides information on the characteristics, functionalities, the advantages, and disadvantages of each technology.

2 Field-Implanted Technology

Field-implanted (or field-inserted) soil moisture and chemical sensors are advanced tools that can be used for precision agriculture and environmental monitoring. These sensors are installed directly into the field, where they can continuously monitor soil moisture levels and chemical composition. They are resilient to environmental conditions and consistently deliver high performance. There is a variety of soil moisture and chemical sensors available on the market. The sensors differ in terms of their detection range, precision, durability, and connectivity options. This means that there is a sensor available to suit a wide range of application requirements. The following criteria were used to select the sensors for this section:

- Market availability:
  - The sensors were selected based on their availability in the market. Factors such as ease of procurement and the after-sales support provided by the manufacturers were considered.

- Price affordability:
  - The sensors were selected to cover a range of price points to cater to different budget constraints.

- Usage references:
  - The sensors with proven track records and positive user feedback were given preference. These sensors have demonstrated their effectiveness in real-world scenarios, offering confidence in their capabilities. In addition, the selection was also based on the references in scientific journals that have used these sensors for various applications and have reported their performance and accuracy. These references provide evidence of the reliability and validity of these sensors for soil moisture monitoring.

- Team experience:
  - The team's personal experience with the sensors played a significant role in the selection process. The selected sensors have been used, tested, and vetted by the team, ensuring that they meet high standards of quality and reliability.

The sensors in this section offer a range of capabilities and advantages. By exploring the options available, readers can make an informed decision that aligns with their specific needs and objectives. The following field-implanted sensors are presented in this section:

- METER 5TE (Section 2.1)
- SENTEK SDI-12 SERIES II Probe (Section 2.2)
- AquaCheck Sub-Surface (Section 2.3)
- Delta-TPR2 (Section 2.4)
- Jingxunchangtong (JX IoT) Soil Analyzer-5 in 1 (Section 2.5)
- Campbell CS655 Soil Moisture and Temperature Sensor (Section 2.6)
- The RiTx Jinawi Sensor (Section 2.7)

2.1 Sensor 1: METER 5TE

Full Name of Sensor

METER 5TE Volumetric Water Content (VWC), Temperature, and Electrical Conductivity (EC) and ZL6 Data logger

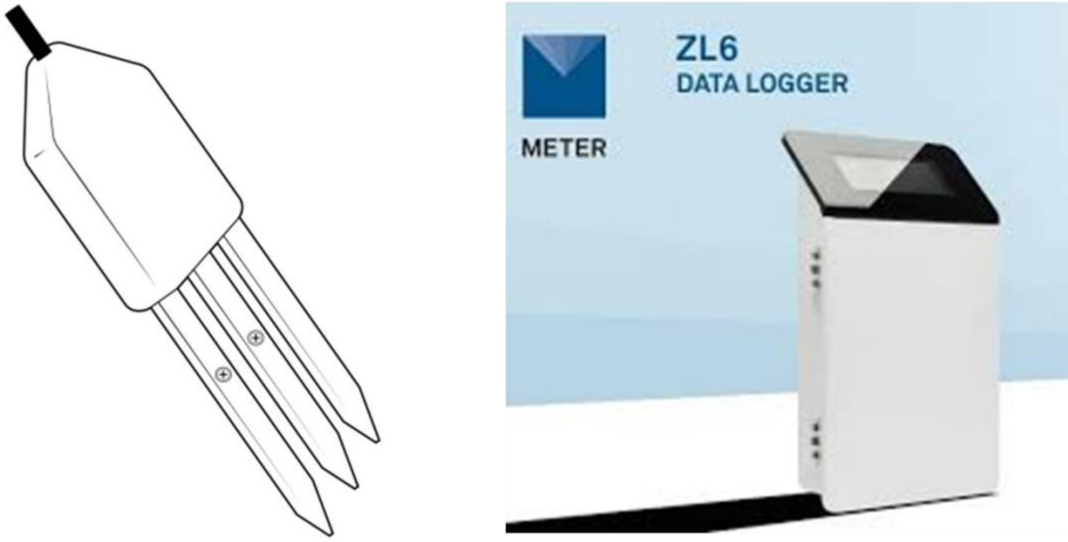

Figure 1 5TE Volumetric Water Content (VWC), Temperature, and Electrical Conductivity (EC) (left) and ZL6 Data logger (right)

Sensor Characteristics

The 5TE uses a two-sensor array to measure the EC. The array is located on the screws of two of the 5TE prongs. 5TE EC measurements are normalized to 25 °C This sensor provides information on volumetric water content, temperature, and electrical conductivity in the soil. This information can be used to monitor soil water status and soil chemical contents and estimate the availability of nutrients in soils with certain properties.

The ability of a substance to conduct electricity and can be used to infer the amount of charged molecules that are in solution such as soil water, nutrient solution, and pure water. The sensors measure EC by applying an alternating electrical current to two electrodes and measuring the resistance between them. Conductivity is then derived by multiplying the inverse of the resistance (conductance) by the cell constant (the ratio of the distance between the electrodes to their area).

The 5TE sensor uses an electromagnetic field to measure the dielectric permittivity of the surrounding medium. The sensor supplies a 70 MHz oscillating wave to the sensor prongs those charges according to the dielectric of the material. The stored charge is proportional to soil dielectric and soil VWC. The 5TE microprocessor measures the charge and outputs a value of dielectric permittivity from the sensor.

Data Frequency

With the provided data logger, the system can supply data as rapid as 1 data per minute.

Communication Architecture

Output sensor is DDI serial or SDI-12 communication protocol with Data Logger Compatibility Form Data acquisition systems capable of 3.6- to 15.0-VDC power and serial or SDI-12 communication. When using serial communication, the 5TE makes a measurement when excitation voltage is applied. Within about 120 ms of excitation, three measurement values are transmitted to the data logger as a serial stream of ASCII characters. The serial out is 1200 baud asynchronous with 8 data bits, no parity, and 1 stop bit. The voltage levels are 0 to 3.6 V and the logic levels are TTL (active low). The power must be removed and reapplied for a new set of values to be transmitted. The ASCII stream contains three numbers separated by spaces. The stream is terminated with the carriage return character. The first number is raw dielectric output. The second number is EC, and the third number is raw temperature. The following explains how to convert the raw values into their standard units. The raw dielectric value (εRaw) is valid in the range 0 to 4094. This corresponds to dielectric permittivity values 0.00 to 81.88. The 5TE uses the εRaw value of 4095 to indicate the dielectric permittivity portion of the sensor is not working as expected.

Transmission Characteristics

The 5TE sensor uses capacitance technology. It outputs an SDI-12 signal that many data loggers can measure. The transmission of the 5TE sensor is: SDI-12 or DDI serial interface Cable Length 5 m (standard) or 75 m (maximum custom cable length) with Connector Types 3.5-mm stereo plug connector or stripped and tinned wires.

Power Requirement

Supply Voltage (VCC to GND) 3.6 VDC - 15.0 VDC, Digital Input Voltage (logic high) 2.8 V - 3.9 V, Digital Input Voltage (logic low) 0.3 V - 0.8 V, Power Line Slew Rate 1.0 V/ms, Current Drain (during measurement) 0.5 mA - 10.0 mA, Current Drain (while asleep) Typical 0.03 mA, Power-Up Time (DDI serial) 100 ms, Power-Up Time (SDI-12) 100 ms - 200 ms, Measurement Duration 200 ms.

Geographic Operationality and Performance Standard

The Meter 5TE sensor and ZL6 data logger can operate in various geographic locations and environmental conditions if they are installed and maintained correctly. Their performance will depend on factors such as soil type, temperature, moisture, and electrical conductivity.

Additional Infrastructure Requirement

- Sensor installation accessories:
  - Accessories such as augers or soil corers to create holes of the appropriate size and depth, cable ties, stakes, brackets to secure the sensors and cables in place.
  - Weatherproof enclosures to protect the ZL6 data logger and its components from environmental elements like dust, rain, or extreme temperatures, you may need a weatherproof enclosure.

Estimated Cost

- Sensor cost:
  - approximately $200-$250 per sensor.
- Data logger cost:
  - EM50: approximately $600
  - EM60: approximately $800
  - ZL6: approximately $1,000

Links

- https://www.metergroup.com/environment/products/5tm-moisture-and-temperature-sensor/

Other Sensors from the Brand

- TEROS 12:
  - A digital multi-parameter soil sensor that measures soil moisture, temperature and electrical conductivity using SDI-12 interface.
  - It has a large volume of influence and a low power requirement.
- TEROS 21:
  - A soil water potential sensor that measures soil matric potential using a ceramic tensiometer.
  - It has a wide measurement range and a fast response time.
- EC-5:
  - A simple and affordable soil moisture sensor that measures soil water content using a 70 MHz frequency.
  - It has a small volume of influence and minimal salinity and textural effects.
- MPS-6:
  - A soil water potential sensor that measures soil matric potential using a chilled-mirror dew point technique.
  - It has a high accuracy and a long-term stability.

2.2 Sensor 2: SENTEK SDI-12 SERIES II Probe

Full Name of Sensor

SENTEK SDI-12 SERIES II Probe

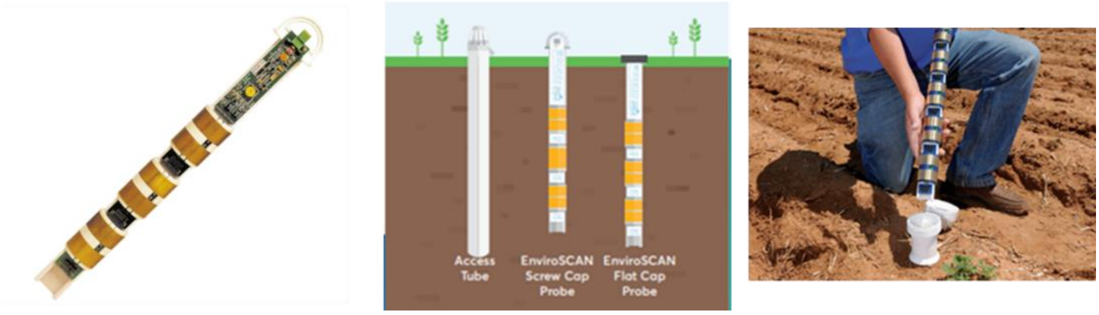

Figure 2 SENTEK SDI-12 SERIES II Probe (left), Installation schematic (mid), installation picture (right)

Sensor Characteristics

EnviroSCAN probe is the only commercially available product that can monitor soil moisture, salinity, temperature, and humidity at depths from 0.5 metres to 40 metres. EnviroSCAN can be used for vineyards, tree crops, research projects, irrigated and dryland crops as well as environmental and landscape management.

The sensor consists of an access tube with multiple capacitance sensors positioned at different depths along the tube. This allows for continuous measurement of soil moisture at various levels in the soil profile. Each capacitance sensor has two conductive plates embedded in the probe. When an electromagnetic field is generated between these plates, it interacts with the surrounding soil.

This equipment has been tested and found to comply with the limits for digital device, pursuant to part 15 of the FCC (Federal Communications Commission) rules hat govern the use of radio frequency (RF) devices in the United States. These limits are designed to provide reasonable protection against harmful interference in a residential installation. This equipment generates, uses, and can radiate radio frequency energy and, if not installed and used in accordance with the instructions, may cause harmful interference to radio communications.

Data Frequency

The EnviroSCAN and EasyAG SDI-12 probe interface currently uses a fixed format of "sign followed by three digits, followed by the decimal point, followed by four decimal digits" (±nnn.nnnn) to return readings. This may change in future issues of the EnviroSCAN or EasyAG SDI-12 probe interface firmware (software should not rely on this fixed format). Valid soil moisture values will always be in the range +000.0000 to +101.0000. Soil moisture data which would result in values in the range -0.1 to 0.0 will be returned as +000.0000. Any soil moisture values outside of this range (caused by faulty sensors, incorrect probe installation or configuration) will be returned as -999.9999. A failed sensor will also return a value of -999.9999. The sensor can produce one data in 50mS for Moisture and 90mS for TriSCAN (moisture, temperature, and salinity).

Communication Architecture

The sensor has Flexible connectivity for wide range of data retrieval options. This section provides information about the SDI-12 communication protocol used by the EnviroSCAN and EasyAG SDI-12 probe interfaces.

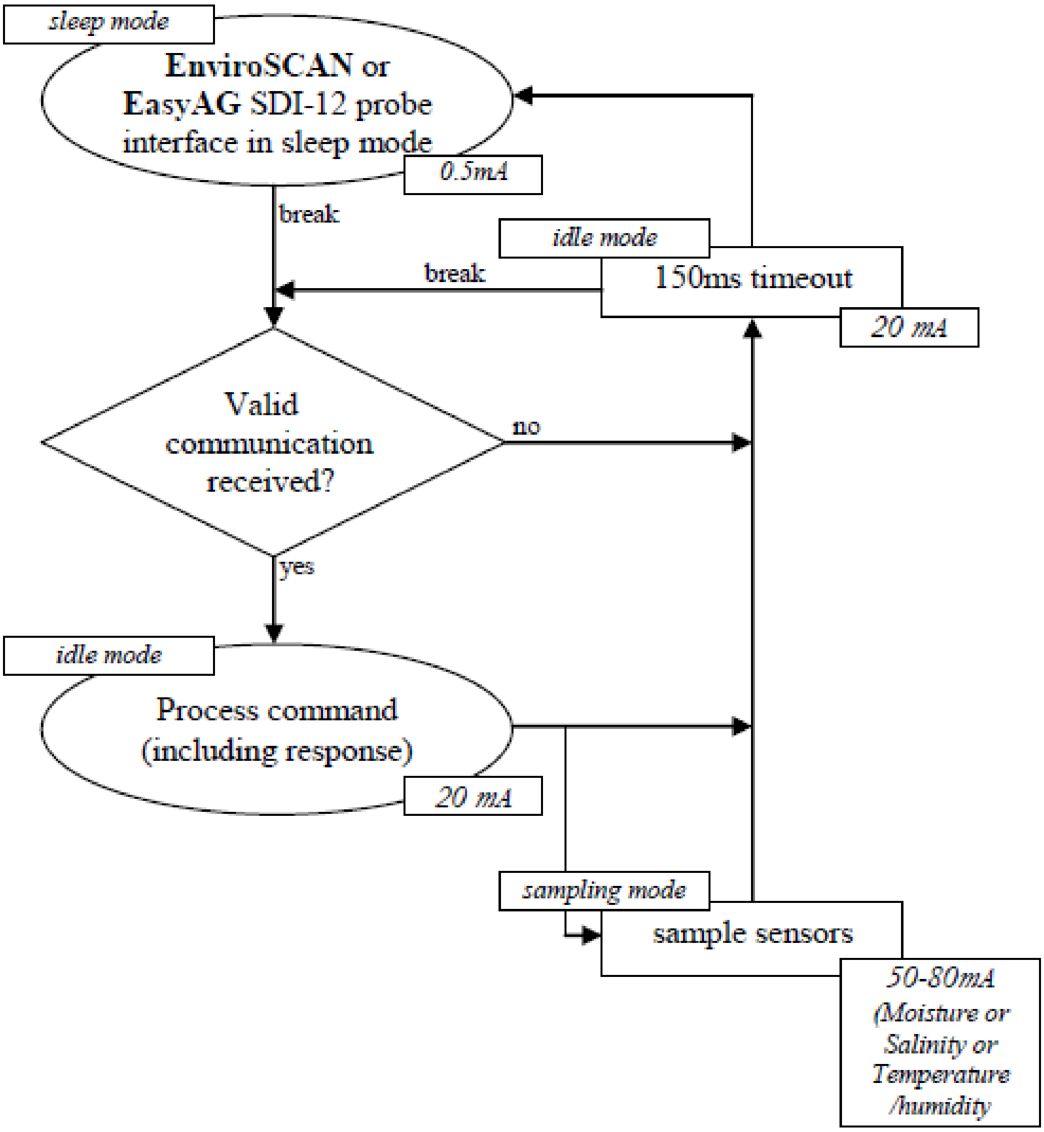

Figure 3 Sentek SDI-12 probe interface communication power sequence.

The EnviroSCAN and EasyAG SDI-12 probe interface stores a 64-bit serial number. The Probe Configuration Utility will report all 64 bits as a hexadecimal number. The first two digits (8 bits) of this serial number are always "10" or "01", and the last two digits (8 bits) are a Cyclic Redundancy Check (CRC). The serial number reported via SDI-12 omits the first and last 8 bits, providing the remaining 48 bits as the serial number.

Transmission Characteristics

The sensor transmission includes the use of communication protocol: SDI-12, Maximum number of sensors:16, Electrical power consumption: current 500μA (@

sleep 100mA), voltage @ sampling 12VDC with flexible options of connectivity and data retrieval options provided by Sentek.

Power Requirement

EnviroSCAN Current consumption are typical initial power on characteristic at 5.5V is maximum current draw 200mA and the interface enters the idle state after about 120ms. These two graphs were prepared from a sample EnviroSCAN PCB revision 2.4 manufactured in 2012. Other revisions may have slightly different characteristics.

Geographic Operationality and Performance Standard

The Sentek SDI-12 Series II Probe can be deployed in various environments and climates, making it suitable for use in diverse geographic locations. It can withstand temperature extremes and high levels of moisture, ensuring reliable performance in different weather conditions.

Additional Infrastructure Requirement

- Compatible data logger:
  - A data logger, such as the Sentek Solo or Sentek Plus, or a compatible third-party data logger with SDI-12 or RS485 interface, to record and store the measurement data.
- Telemetry System for remote measurement.
- Power Source required for the data logger and telemetry system. A solar panel with a charge controller and battery can be used, or a mains power supply.
- Mounting equipment:
  - brackets, poles, or other hardware is needed to secure the data logger, telemetry system, and power system in the field.
- Cabling and Connectors to connect the probe to the data logger and telemetry system, the power source to these devices.
- Software:
  - Sentek provides the IrriMAX software for processing, analysing, and visualizing collected data to make informed irrigation and water management decisions.
- Probe Installation at the site, typically involves digging a hole, inserting the probe, and backfilling the hole with the excavated soil, followed by proper compaction.
- Weather Protection such as enclosures or covers for the data logger, telemetry system, and power source.

Estimated Cost

- Sensor cost:
  - approximately $1,500-$2,000 per probe (multi-sensor probe).
- Data logger cost:

- Solo: approximately $500
- Plus: approximately $1,000
- Multi: approximately $1,500

Links

- https://sentek.com.au/
- https://sentektechnologies.com/products/soil-data-probes/enviroscan/

Other Sensors from the Brand

- EnviroSCAN:
  - A soil moisture, salinity, temperature, and humidity profile sensor that can monitor up to 40 metres deep using capacitance technology.
- Drill & Drop:
  - A soil moisture, temperature and salinity sensor that can be easily installed in a drilled hole using capacitance technology.
- Drill & Drop Bluetooth:
  - A soil moisture sensor that can be connected to a smartphone or tablet via Bluetooth for easy data access using capacitance technology.
- Diviner 2000:
  - A portable soil moisture sensor that can measure water content at different depths using a probe and a handheld unit.

2.3 Sensor 3: AquaCheck Sub-Surface

Full Name of Sensor

AquaCheck Sub-Surface and Classic series probes

Figure 4 AquaCheck Sub-Surface Sensor

Sensor Characteristics

The AquaCheck Sub-Surface probe is a capacitance-based soil moisture and soil temperature monitoring device offering up to 15 sensors per probe. The Sub-Surface probe requires an external logger or remote transmission unit and external power supply.

The Aquacheck Subsurface and Classic probe range are supplied with wire ends or connectors to communicate and power the probe. There are 2 hardware options: SDI and RS485. RS485 is a "special order" and must be specified on the order, it is not field changeable. There are also 2 software "protocols" available, SDI-12 and MODBUS. The possible configurations are thus SDI-12, SDI-12 over RS485, MODBUS over SDI or MODBUS over RS485. Subsurface probes are provided standard with a 5m cable tail. Classic probes are provided with a friction-lock connector and optionally a cable tail with the female connector fitted. For proper probe installation refer to the Aquacheck user guide.

Data Frequency

The Aquacheck sensor is a soil moisture and temperature sensor that uses capacitance technology to measure the dielectric constant of the soil, which is directly related to soil water content. It can measure up to 15 sensors per probe at different depths in the soil profile. It requires an external logger or remote transmission unit and external power supply. It can communicate using SDI-12, MODBUS or RS-485 interface options. The data frequency or sampling or recording periods possible for the Aquacheck sensor depend on the data logger or transmission unit that is connected to the sensor. The logger or unit can be programmed to request and record data at different intervals, depending on the application and the storage capacity. the range of possible sampling time may vary from seconds to days.

Communication Architecture

Probes are shipped standard with SDI hardware drivers, RS485 drivers are fitted by "special order". The RS485 drivers are embedded into the probe body, "in-field" changing between RS485, and SDI drivers is not possible. The probe "protocol" is different to the hardware drivers: - for example BOTH MODBUS and SDI-12 protocol can operate over the RS485 drivers. AquaCheck also come with telemetry option.

Transmission Characteristics

The Aquacheck uses SDI-12, MODBUS or RS-485 interface options with Measurement time: 3 ms to measure; 600 ms to complete SDI-12 command. Cable Length 5 m (standard) or 75 m (maximum custom cable length) with Connector Types 3.5-mm stereo plug connector or stripped and tinned wires.

Power Requirement

The power requirement for the sensor is 10uA (0,01mA) during idle; 20mA for 2 seconds during measurement, with voltage input: 4-14V. Power may be supplied continuously, or as needed.

When power is supplied, the controller must wait at least one second before communicating on the bus. It is important that the bus be held in the "idle" state (below 1V for SDI bus and in the "spacing" state for RS485 versions). If power is removed between readings, it is important to remove the power for at least 1 minute so the probe will properly wake on the next power sequence. If communication with the probe is less than one-minute intervals, then keep the power applied. If the controller requests readings at a rate faster than one minute, the probe would return the last valid reading. It is not possible to read the sensors at a rate faster than one minute.

It is important to note that AquaCheck probes support very low-power (battery-operated) systems. The probe can accept supply voltages as low as 3.3V. The SDI-12 specification requires the data line to operate between 0V and 5V. The user needs to take note that when the probe is supplied with less than 5V the data line will operate at a lower "marking" voltage than 5V. For supplies between 3.3V and 5V the "marking" voltage on the data line will equal the supply voltage less 0.2V. If the RTU expects 5V on the data line, then the probe must be powered with at least 5V.

Geographic Operationality and Performance Standard

The AquaCheck probe's design and compatibility features make it suitable for operation in various geographic regions. Operating Temperature Range –40 °C to 60 °C., It is essential to ensure proper installation, maintenance, and calibration to optimize its performance in different environments.

Additional Infrastructure Requirement

- Data Logger:
  - A compatible data logger is needed, such as the AquaCheck CCII data logger or another third-party data logger with an SDI-12 interface, to record and store soil moisture data.
- Telemetry System:
  - To enable remote data access and monitoring, a telemetry system, such as cellular, radio, or satellite communication systems, depending on your location and data transmission needs will be required.
- Power Source:
  - A suitable power source for the probe and data logger, which could be solar panels, battery packs, or mains power, depending on the site conditions and availability of resources will be required.
- Mounting Equipment:
  - Mounting equipment, such as brackets, poles, or enclosures, to secure the data logger, telemetry system, and power source, protecting them from weather elements and potential damage may be required.
- Cabling and Connectors:
  - Appropriate cabling and connectors to link the AquaCheck probe to the data logger, telemetry system, and power source, ensuring secure and reliable data transmission and power supply will be needed.
- Installation Tools:
  - Depending on the soil type and site conditions, specific tools, such as an auger or soil corer, to facilitate the installation of the AquaCheck probe at the desired depth may be needed.
- Calibration Equipment:
  - To ensure accurate soil moisture measurements, calibration equipment, such as reference soil moisture sensors or gravimetric sampling tools, to calibrate the AquaCheck probe for the specific soil type and environmental conditions may be needed.

Estimated Cost

- Sensor cost:
  - approximately $1,000-$1,500 per probe.
- Telemetry unit cost (includes integrated data logger):
  - approximately $800-$1,000.

Links

- https://www.aquacheck.cc/

Other Sensors from the Brand

- Aquacheck Classic:
  - A soil moisture and temperature profile sensor that can monitor up to 1.2 metres deep using capacitance technology.
- Aquacheck Plus:
  - A soil moisture, temperature and salinity profile sensor that can monitor up to 1.2 metres deep using capacitance technology.
- Aquacheck Wireless:
  - A wireless soil moisture and temperature profile sensor that can monitor up to 1.2 metres deep using capacitance technology and LoRa communication.
- Aquacheck Bluetooth:
  - A Bluetooth soil moisture and temperature profile sensor that can monitor up to 1.2 metres deep using capacitance technology and Bluetooth communication.

2.4 Sensor 4: Delta-T PR2

Full Name of Sensor

Delta-T PR2 Profile Probe

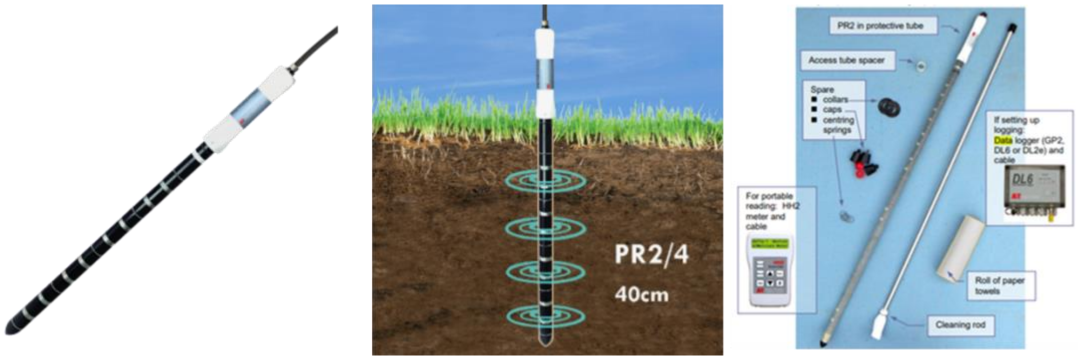

Figure 5 PR2 Probe (left), sensor installation in soil (mid), accessories including protective tube, meter and cable, data logger (right)

Sensor Characteristics

The PR2 Profile Probe is a soil moisture sensor that can measure the moisture content of soil at different depths. It can be used as a portable probe or installed in an access tube for continuous monitoring. The PR2 Profile Probe has two versions: analogue and SDI-12. The analogue version can be connected to a data logger such as the DL6 or GP2, while the SDI-12 version can be integrated into any SDI-12 compatible system. The PR2 Profile Probe has six or four sensors spaced along a 1m or 0.6m length of probe. It uses capacitance technology to measure the dielectric constant of the soil, which is related to the water content. The PR2 Profile Probe is accurate, reliable, and easy to use.

The unique PR2 Profile Probe can be installed for continuous data logging and also be used for multi-site, portable measurements. The PR2 soil moisture probe is built around patented sensing technology which provides unprecedented performance in all soil types, with minimal influence from either salinity or temperature. The PR2/4 model measures soil moisture at 4 depths down to 40 cm – the PR2/6 measures at 6 depths down to 100 cm.

For portable uses, moisture meters HH2 is used. HH2 reads and stores the soil moisture content at either 4 or 6 depths simultaneously and can calculate the water deficit. The HH2 auto-detects the number of sensors present in each Profile Probe. Customers who already have an HH2 Readout Unit will require an upgrade prior to using it with a PR2. User-defined soil types of Standard, generalised calibrations for mineral and organic soils are supplied with the HH2. The software also permits up to 5 extra user-defined soil calibrations to be characterised and stored for later use.

The HH2 automatically calculates the water deficit, based on data from the individual sensors of a PR2. This indicates the amount of water needed (in mm) to restore the plot to field capacity, down to a user-defined rooting depth. (Requires field capacity value to be input).

Data Frequency

The SDI-12 standard data rate id 1200 baud (120 character per second), While using GP2 data logger may take 3 seconds to 12 seconds depend on number of sensors and mode used.

Communication Architecture

SDI-12 is an established communication standard adopted by many manufacturers of environmental monitoring and control equipment. It is popular because it allows large numbers of sensors (from many vendors) to be connected to a logger via a simple cable network, thereby reducing the cost and complexity of wiring large sensor installations. The PR2 SDI-12 conforms to the industry standard SDI-12 (v1.3) specification.

Profile Probes are available with analogue or SDI-12 outputs. For the analogue version, order PR2/4 or PR2/6. For the SDI-12 interface version, order PR2/4-SDI-12 or PR2/6-SDI-12. That analogue and SDI-12 probes cannot be mixed on the same cable system.

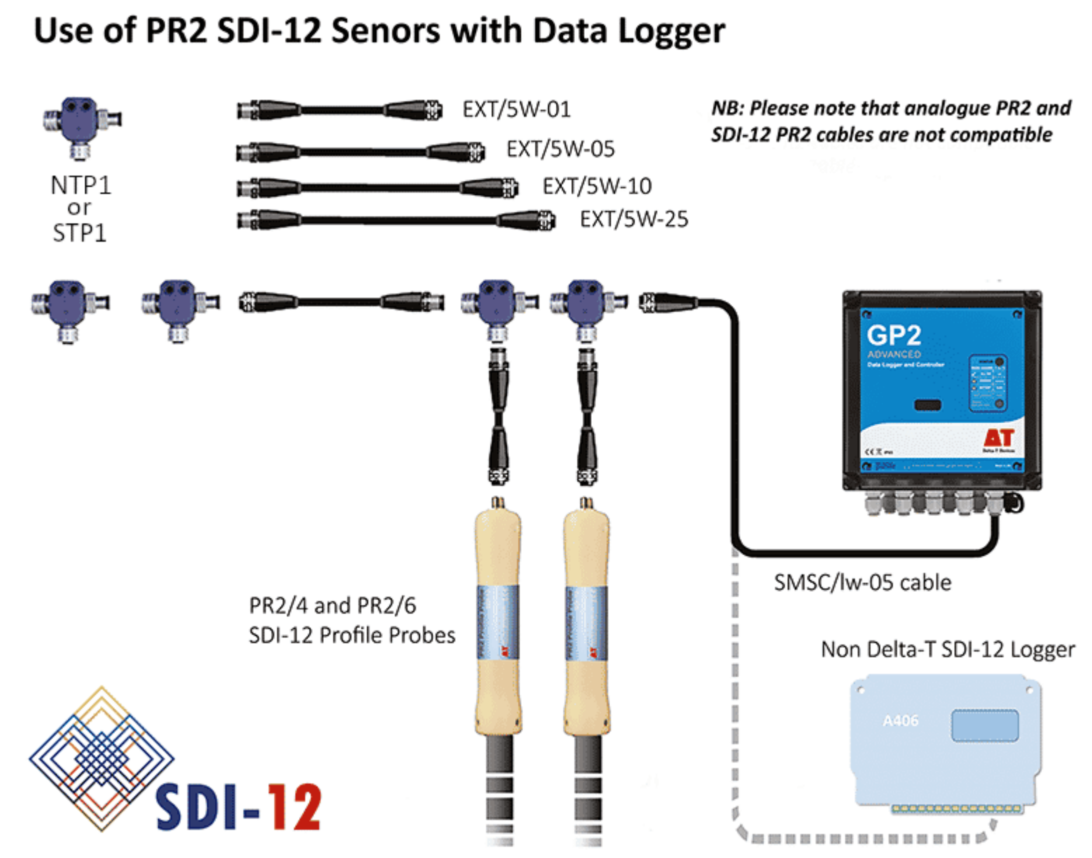

Figure 6 The use of SDI 12 PR2 with GP2 or SDI 12 compatible devices.

Transmission Characteristics

The PR2 SDI-12 has a high-quality, stainless steel IP67-rated connector (M12 x 5-way) – connecting to the standard Delta-T range of M12 x 5-way cables and accessories. The M12 x 8-way range of cables used for analogue PR2 connection is not compatible with the SDI-12 version of the PR2. Analogue and SDI-12 sensors cannot be mixed on the same cable system. All Profile Probes come fitted with an IP68 connector and are supplied with a user manual, protective tube, spare centring springs and O-rings.

Power Requirement

Minimum power input 5.5V DC with 2m cable, 7.5V with 100m and Maximum input 15V DC. PR2/4 consumption < 80 mA, PR2/6 consumption < 120 mA, then 4 (PR2/4) or 6 (PR2/6) analogue voltage outputs are 0 to 1.0V DC corresponding to 0 to 0.6 m3m-3 (mineral calibration).

Geographic Operationality and Performance Standard

The PR2 sensor can be used in various soil or geographical conditions, such as Mineral and organic soils, Saline soils (50 to 400 $mS.m^{-1}$, 0.5 to 4 $dS.m^{-1}$, pore water conductivity), Temperate and tropical climates (0 to 40ºC for full accuracy specification, -20 to +70ºC full operating range), Flat and sloped terrains, Indoor and outdoor environments. The PR2 sensor is designed to work reliably and accurately in a wide range of soil types and conditions, with minimal influence from salinity or temperature.

Additional Infrastructure Requirement

Delta-T auguring kits help you achieve the best possible access tube installation in virtually any soil. Profile Probes are used in access tubes inserted into carefully pre-augured holes in the soil. Correct access tube installation is vital for accurate measurement of soil moisture profiles. To get the best performance from Profile Probes, the augured holes should be straight, smooth sided and the correct diameter. The goal is to produce optimal contact between the soil and the wall of the access tube. However, if substantial stoniness or compaction, or the presence of voids, foreign bodies, or soil instability are features of a particular site, it may not always be possible to install an access tube successfully.

Estimated Cost

- Sensor cost:
  - approximately $1,500-$2,000 per probe (multi-sensor probe).
- Data logger cost:
  - price varies depending on the data logger model and manufacturer.

Links

- https://delta-t.co.uk/product/pr2/

Other Sensors from the Brand

- WET150:
  - A digital multi-parameter soil sensor that measures soil moisture, temperature and electrical conductivity (EC) using SDI-12 interface.
- SM150T:

- A soil moisture and temperature sensor that uses capacitance technology and offers accuracy of ± 3%.

- ML3 ThetaProbe:
    - A soil moisture and temperature sensor that uses capacitance techpinnology and offers class-leading accuracy of ± 1%.
- WET-2:
    - A sensor that measures moisture and nutrient status in the root zone using a patented dielectric technique.

2.5 Sensor 5: Jingxunchangtong (JX IoT) Soil Analyzer-5 in 1

Full Name of Sensor

Jingxunchangtong (JX IoT) Soil analyzer-5 in 1 soil sensor-soil tester

Figure 7 Jingxunchangtong Soil analyzer-5 in 1 soil sensor-soil tester

Sensor Characteristics

- A soil all-in-one sensor that can simultaneously monitor soil temperature, soil moisture, soil pH, soil electrical conductivity, and soil nitrogen, phosphorus, and potassium.
- Measurement method:
  - TDR (time domain reflectometry) to measure soil temperature, soil moisture, soil pH, soil electrical conductivity (EC), soil nitrogen (N), phosphorus (P) and potassium (K).

Table 1 Sensor characteristics

Parameter	Parameter Content
Power supply	12-24V DC
Output Signal	RS485/4G/NB-IIoT/LoRa
Installation method	Fully buried or all probes are inserted into the measured medium
Protection level	IP68
Response time	<1s
Range of moisture	0~100%
Accuracy of moisture	• Reading ±3% (0~53%)

Parameter	Parameter Content
	• Reading ±5% (53~100%)
Range of Temp.	-40°C~80°C
Accuracy of Temp.	±0.5°C
Conductivity measurement range	0-10000us/cm
Conductivity resolution	10us/cm
PH measuring range	3-9PH
PH measurement accuracy	±0.3PH
NPK measurement range	0-1999 mg/kg
NPK measurement accuracy	±2% F.s
Storage environment	-20°C-60°C
Working pressure range	0.9-1.1atm

Data Frequency

The sensor can output data at a user-defined interval, ranging from once per second to once per hour.

Communication Architecture

The sensor supports various communication methods, such as RS485, RS232, SDI-12, Modbus RTU, LoRaWAN, NB-IoT, etc. The sensor can be connected to a data logger, a gateway, a cloud platform, or a mobile app for data transmission and visualization.

Transmission Characteristics:

The sensor has a low power consumption and a high sensitivity. The sensor can transmit data over long distances and through obstacles, depending on the communication method and the environmental conditions. The sensor can work in harsh environments and has a strong anti-interference ability.

Power Requirement:

The sensor can be powered by a DC power supply (5V ~ 24V), a solar panel, or a battery. The sensor has a built-in voltage regulator and a reverse polarity protection circuit.

Geographic Operationality and Performance Standard

The sensor can operate in various geographic regions and climates, such as farmland, greenhouses, orchards, etc. The sensor has an IP68 protection level, which means it is waterproof and dustproof. The sensor has passed the CE and RoHS certification.

Additional Infrastructure Requirement

- The sensor does not require any additional infrastructure for installation and operation.
- The sensor can be inserted into the soil directly or mounted on a bracket or a pole.

Estimated Cost

- The sensor costs about $200 USD per unit, excluding shipping and taxes.

Links

- https://jxiotet.com/smart-agriculture/soil-sensor/77.html

Other Sensors from the Brand

- 7 in 1 Integrated Soil Sensor:
  - A portable soil sensor that measures soil moisture, temperature, EC, pH, NPK, and has RFID and GPS functions.
- Digital Soil Meter:
  - A soil sensor that measures soil moisture, temperature, EC, pH, NPK, and has NB-IoT or LoRa transmission.
- Soil EC Sensor:
  - A soil sensor that measures soil electrical conductivity and salinity with high precision and fast response.
- Soil pH Sensor:
  - A soil sensor that measures soil acidity with high accuracy and long-term stability.
- Soil Monitoring System:
  - A system that measures soil temperature, moisture, EC, pH, NPK, and ground water level using RS485 or 4G communication.

2.6 Sensor 6: Campbell CS655 Soil Moisture and Temperature Sensor

Full Name of Sensor

CS655 Soil Moisture and Temperature Sensor

Figure 8 CS655 Soil Moisture and Temperature Sensor

Sensor Characteristics

The CS655 sensor is a soil moisture and temperature sensor that uses capacitance technology to measure soil volumetric-water content, bulk electrical conductivity, and temperature. It outputs an SDI-12 signal that many data loggers can measure the sensor consists of two 12-cm-long stainless-steel rods connected to a printed circuit board that is encapsulated in epoxy. The sensor measures propagation time, signal attenuation, and temperature of the soil. The sensor derives dielectric permittivity, volumetric water content, and bulk electrical conductivity from these raw values. The sensor uses measured signal attenuation to correct for the loss effect on reflection detection and thus propagation time measurement.

The sensor allows accurate water content measurements in soils with bulk EC ≤8 dS m -1 without performing a soil-specific calibration. The sensor has a thermistor in thermal contact with a probe rod near the epoxy surface that measures temperature. The sensor outputs an SDI-12 signal that many data loggers can measure.

Data Frequency

The sensor has a measurement time of 3 ms to measure and 600 ms to complete SDI-12 command.

Communication Architecture

The sensor uses SDI-12; serial RS-232 for communication.

Transmission Characteristics

- The sensor has a power supply requirement of 6 to 18 Vdc (Must be able to supply 45 mA @ 12 Vdc).
- The sensor has a maximum cable length of 610 m (2000 ft) combined length for up to 25 sensors connected to the same data logger control port.

Power Requirement

The sensor does not have a built-in power backup system, so it relies on the external power supply from the data logger or other sources.

Geographic Operationality and Performance Standard

- The sensor has an operating temperature range of -50° to +70°C.
- The sensor is CE compliant (Meets EN61326 requirements for protection against electrostatic discharge and surge)
- The sensor is suitable for soils with higher electrical conductivity.

Additional Infrastructure Requirement

- The sensor requires a measurement system such as a data logger or a handheld device to collect and store data.
- The sensor may require an optional installation tool (CS650G Rod Insertion Guide Tool) to insert the rods in dense or rocky soils.

Estimated Cost

- CS655 Sensor: $795
- CS650G Rod Insertion Guide Tool: $125
- Cable (per foot): $0.85

Links

- https://www.campbellsci.com/cs655

Other Sensors from the Brand

- CS650:
  - A soil moisture and temperature sensor that uses capacitance technology to measure soil volumetric water content, bulk electrical conductivity, and temperature.
  - It has longer rods than the CS655, for use in soils with low to moderate electrical conductivity.
- CS616:

- A soil moisture sensor that uses a 70 MHz frequency to measure the volumetric water content of porous media (such as soil).
- It has long rods and lower frequency that are well-suited for soft soil with low electrical conductivity.

- SoilVUE10:
  - A soil moisture and temperature profile sensor that uses TDR technology to measure volumetric water content, permittivity, electrical conductivity, and temperature at six or nine depths with one sensor.

2.7 Sensor 7: The RiTx Jinawi Sensor

Full Name of Sensor

RiTx Jinawi sensor

Figure 9 RiTx Jinawi sensor

Sensor Characteristic

The RiTx Jinawi sensor, provided by MSMB Indonesia, is a device that measures the levels of N, P, K and pH in the soil using a capacitance technique, available in local market Indonesia. It has a stainless-steel rod that is inserted into the soil and a plastic casing that contains the electronics and the battery. It has a LED indicator that shows the status of the sensor and the battery. It has a Bluetooth module that allows wireless communication with the RiTx Bertani application on a smartphone or tablet.

Data Frequency

The RiTx Jinawi sensor can measure the soil parameters every 10 seconds and send the data to the RiTx Bertani application via Bluetooth. The application can store the data locally on the device or upload it to a cloud server for further analysis and visualization. The data frequency can be adjusted by the user according to their needs and preferences.

Communication Architecture

The RiTx Jinawi sensor uses Bluetooth 4.0 technology to communicate with the RiTx Bertani application on a smartphone or tablet. The Bluetooth range is about 10 meters, depending on the environment and interference. The application can connect to multiple sensors at once and display their data on a map or a graph. The application can also connect to the internet via Wi-Fi or cellular network and upload the data to a cloud server for further analysis and visualization.

Transmission Characteristics

The RiTx Jinawi sensor uses Bluetooth 4.0 technology to transmit data to the RiTx Bertani application. The Bluetooth protocol uses frequency hopping spread spectrum (FHSS) technique to avoid interference and increase security. The Bluetooth data rate is up to 1 Mbps, depending on the distance and environment. The Bluetooth power consumption is low, as it uses short packets and low duty cycles.

Power Requirement

The RiTx Jinawi sensor uses a 3.7 V rechargeable lithium-ion battery as its power source. The battery capacity is 1000 mAh, which can last for about 6 months of continuous operation, depending on the data frequency and environmental conditions. The battery can be recharged using a micro-USB cable connected to a power adapter or a computer. The sensor has a low battery warning feature that alerts the user when the battery level is below 20%.

Geographic Operationality and Performance Standard

The RiTx Jinawi sensor can operate in various geographic regions and soil types, as it uses a capacitance technique that minimizes textural and salinity effects on the measurements. The sensor can measure soil parameters in a range of 0-1000 ppm for N, 0-100 ppm for P, 0-1000 ppm for K, and 1-14 for pH, with an accuracy of ±10% for N, P, K, and ±0.2 for pH. The sensor can withstand temperatures from -20°C to +60°C and humidity from 0% to 100% RH.

Additional Infrastructure Requirement

The RiTx Jinawi sensor requires an external logger or remote transmission unit and external power supply. It also requires a smartphone or tablet with Android operating system and Bluetooth capability to run the RiTx Bertani application. The application requires internet access via Wi-Fi or cellular network to upload data to a cloud server for further analysis and visualization.

Estimated Cost

- The RiTx Jinawi sensor costs Rp 17.500.000 for the basic package, which includes one controller, one pH sensor, one NPK sensor, and one fertilization recommendation for one crop type.
- The pro package costs Rp 45.000.000, which includes one controller, one pH sensor, one NPK sensor, five fertilization recommendations for five crop types, one year of data management service, and dashboard access.

These prices do not include VAT 11%.

Links

- https://msmbindonesia.com/jinawi/
- https://msmbindonesia.com/pemupukan-berimbang-jinawi/

Other Sensors from the Brand

MSMB Indonesia does not offers other sensors, however they have smart farming solutions RiTx Bertan, A smart farming application that provides various features such as crop calendar, weather forecast, pest and disease identification, market information, etc.

3 Remote Sensing Technology

Choosing the right satellite for soil moisture and chemical detection is crucial and involves several considerations, as detailed in this chapter. The selection of satellites is based on unique capabilities, ease of data access, expert recommendations, and suitability for use in Indonesia. The distinct strengths of each satellite, such as specialised measurements and the broader dataset, are key considerations. However, balancing these strengths with the specific needs of soil sensing was our main objective.

Availability of data is crucial, such as satellites that offer data freely to the public, making them an invaluable resource. The list is also guided by expert opinions from fields like remote sensing and agriculture, vouching for the reliability of these satellites in soil detection. Considering our focus on Indonesia, the satellites' geographical operationality was scrutinized to ensure effective coverage. This curated list of satellites aims to guide stakeholders in Indonesia to harness satellite remote sensing for climate-smart agriculture.

The following satellite technologies are presented in this section:

- Soil Moisture and Ocean Salinity (SMOS) (Section 3.1)
- ESA Sentinal 2 (Section 3.2)
- Landsat 8 (Section 3.3)
- Landsat 9 (Section 3.4)
- Sentinel 1 (Section 3.5)
- Sentinel 3 (Section 3.6)
- ASCAT (Section 3.7)
- MODIS (Section 3.8)
- SMAP Satellite (Section 3.9)
- Dove CubeSats (Section 3.10)

3.1 Satellite 1: Soil Moisture and Ocean Salinity (SMOS)

Full Name of Satellite

Soil Moisture and Ocean Salinity (SMOS)

Figure 10 Soil Moisture and Ocean Salinity (SMOS) Satelite

Sensor Characteristics

The SMOS satellite carries a new type of instrument called Microwave Imaging Radiometer with Aperture Synthesis (MIRAS). Some eight metres across, it has the look of helicopter rotor blades; the instrument creates images of radiation emitted in the microwave L-band (1.4 GHz). MIRAS will measure changes in the wetness of the land and in the salinity of seawater by observing variations in the natural microwave emission coming up off the surface of the planet. The output data is surface soil moisture with an accuracy of 4% (at 35–50 km spatial resolution)

The principle is to find the best-suited set of soil moisture (SM) and vegetation characteristics by minimizing the differences between modelled direct and measured brightness temperature (TB) data. Other potential methods are:

- Direct retrieval. However, direct retrieval is not feasible because the relationship between SM and TB is not unique. Moreover, direct retrieval would not allow accounting for the heterogeneous characteristics of the pixels.
- Empirical / statistical approaches where a regression is built between SM and TBs.
- Neural network approaches.

- The main issue with statistical and neural network approaches is that in the SMOS case it will require measurements and can only be implemented sometime after launch.

Satellite Characteristics

Table 2 Satellite characteristics

Characteristic	Description
Mission type	EO
Agency	ESA, CNES, CDTI
Mission status	Operational (nominal)
Launch date	02 Nov 2009
End-of-life date	31 Dec 2021
Measurement domain	Land, Ocean
Measurement category	Soil moisture, Ocean Salinity
Measurement detailed	Sea Surface salinity, Soil moisture at the surface
Instruments	MIRAS (SMOS)
Instrument type	Imaging multi-spectral radiometers (passive microwave)
Spacecraft mass	Launch mass of 670 kg • Platform: 312 kg • Payload: 355 kg
Spacecraft power	Up to 1065 W (511 W available for payload); 78 AH Li-ion battery
Mission duration	Minimum of 3 years
Spacecraft bus	Proteus platform of CNES
Payload interface	Dedicated MIL-STD 1553 bus, 160 kbit/s + dedicated TM/TC
Data storage	500 Mbit bus + 2 Gbit for payload data at EOL (End of Life)
Spacecraft Operations & Control Centre	CNES, Toulouse, France
Payload Mission and Data Centre	ESAC, Villafranca, Spain
RF communications	S-band for TT&C support, downlink data rate at 722 kbit/s, uplink at 4 kbit/s X-band for science data acquisition, Downlink data rate at 18.4 Mbit/s

Data Frequency

SMOS revisit time is about 3 days and so the data frequency is 1 image/3 days for each area of interest.

Communication Architecture

The SMOS satellite communicates with the ground stations using S-band radio frequencies. The data received by the ground stations is then processed and distributed to users around the world. The SMOS mission also uses a dedicated data processing centre located in Spain to process and archive the data. This centre receives data from the ground stations and performs the necessary processing to convert the raw data into usable soil moisture and ocean salinity measurements.

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Transmission Characteristics

The transmission characteristics of the SMOS mission's instrument are affected by various factors, including atmospheric conditions and the physical properties of the Earth's surface. For example, the presence of vegetation or snow cover can affect the ability of the instrument to measure soil moisture accurately.

Geographic Operationality and Performance Standard

The SMOS mission is designed to operate in a variety of geographic locations, including areas with different types of terrain, land cover, and ocean conditions. The instrument can measure soil moisture and ocean salinity in a wide range of conditions, including areas with vegetation cover, deserts, and polar regions.

When land and water are mixed in the same pixel, the SMOS sensor cannot distinguish between the two and the soil moisture measurement will be inaccurate. This impacts the use of SMOS in Indonesia, which is a country with a long coastline. In Indonesia, SMOS data can be used to monitor soil moisture in inland areas, but it is not reliable for coastal areas. In Indonesia, the best way to monitor soil moisture in coastal areas is to use a combination other satellite or near ground measurement which can measure with higher pixel resolution.

At the SMOS scale (25-60 km), pixels are not uniform, and we may have a variety of surface types, for instance, a rural area with towns and roads, bare fields, fallow land and some crops, thickets or woodland, the occasional river or pond, and again, in the worst case, snow here and there with frozen grounds in some places.

In such cases, the total brightness temperature comes from several classes of emitters. This composite brightness temperature is obtained through an aggregated forward model that combines each class of emitting sources weighted by their intra-pixel cover fractions.

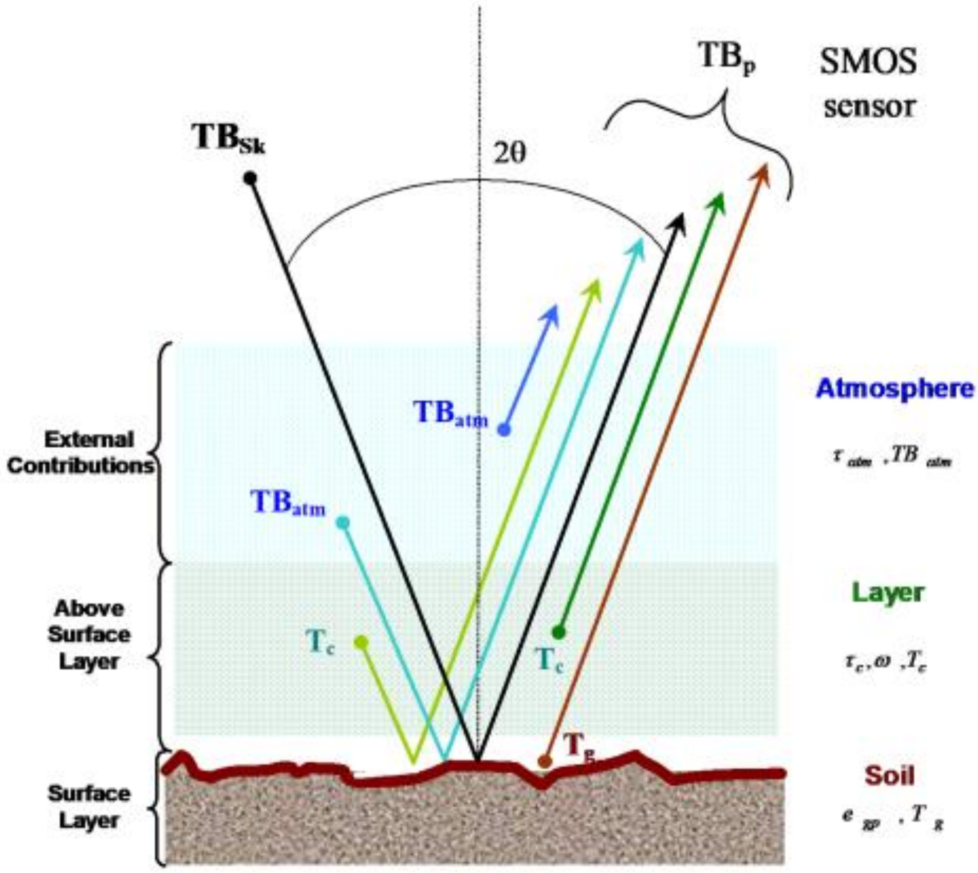

Figure 11 Contributions to TOA (Top of Atmosphere) brightness temperature

Additional Infrastructure Requirement

A computer with internet access and sufficient storage space to download and process the SMOS data, which are freely and openly available from ESA's Earth Online portal1. A software tool for visualising, processing and analysing SMOS data, such as SMOS Toolbox2, SMOS Data Viewer3, SMOS-IC4, or Google Earth Engine.

Estimated Cost

The estimated cost for using the data SMOS is free, excluding the cost of infrastructure.

3.2 Satellite 2: ESA Sentinel 2

Full Name of Satellite

ESA Sentinel 2

Figure 12 ESA Sentinel 2

Sensor Characteristics

The sensors on the Sentinel 2 have several characteristics:

- Multispectral imaging:
  - The Sentinel-2 sensors have 13 spectral bands that cover a wide range of the electromagnetic spectrum, from visible light to shortwave infrared.
  - This multispectral imaging capability allows for detailed analysis of vegetation health, land use changes, soil moisture index and other environmental variables.
- High spatial resolution:
  - The Sentinel-2 sensors have a spatial resolution of 10 meters for band 2, 3, 4 and 8, 20 meters for band 5, 6, 7, 8a, 11 and 12, and 60 meters for band 1, 9 and 10, which allows for detailed mapping of land cover and land use at a local scale.
- Wide swath width:
  - The Sentinel-2 sensors have a wide swath width of 290 km, which allows for large areas of the Earth's surface to be imaged in a single pass.
- Revisit time:

- The combined constellation of Sentinel-2A and 2B mission has a revisit time of 5 days at the equator, which allows for frequent monitoring of changes on the Earth's surface.

- High radiometric resolution:
  - The Sentinel-2 sensors have a radiometric resolution of 12 bits per pixel, which provides high-quality imagery with a wide range of brightness levels.

Satellite Characteristics

Table 3 Satellite characteristics

Characteristic	Description
Launch date	June 23, 2015 (Sentinel-2A) and March 7, 2017 (Sentinel-2B)
Orbit	Sun-synchronous polar orbit at an altitude of approximately 786 km
Mission lifetime	Expected to be 7 years for each satellite
Sensor type	Multispectral imaging sensor
Number of bands	13 spectral bands covering visible, near infrared, and shortwave infrared
Spatial resolution	10 meters and 20 meters for different bands
Swath width	290 km
Revisit time	5 days at the equator
Radiometric resolution	12 bits per pixel

Data Frequency

The data frequency of ESA's Sentinel-2 mission depends on several factors, including the location and size of the area being imaged, cloud cover, and the specific needs of the user. However, the mission's design allows for frequent data acquisition, with a revisit time of 5 days at the equator.

Communication Architecture

ESA's Sentinel-2 mission uses a complex communication architecture to transfer data and commands between the satellites and the ground stations. The communication architecture characteristics for ESA’s Sentinel-2 are satellite-to-ground communication; Ground station network; Data processing and distribution; Mission control. As for ata processing and distribution: Sentinel-2 data is processed and distributed through the Copernicus Open Access Hub and the Sentinel Scientific Data Hub. The raw data is transmitted from the ground stations to the data hubs, where it is processed, calibrated, and made available to users.

Transmission Characteristics

The transmission characteristics of ESA's Sentinel-2 are:

- Data format:

- Sentinel-2 data is transmitted in a compressed format known as JPEG2000.
- This format allows for efficient compression of large amounts of image data without significant loss of image quality.

- Data volume:
  - Sentinel-2 data can generate large amounts of data, with each image covering an area of approximately 290 km x 290 km at a resolution of 10 or 20 meters.
  - To manage this volume of data, the Sentinel-2 mission uses a combination of automated data processing and storage systems and manual quality control and verification processes.
- Latency:
  - The latency, or delay, between data acquisition and availability to users is typically 24-48 hours.
  - This allows for the processing and calibration of the raw data before it is made available through the Copernicus Open Access Hub and the Sentinel Scientific Data Hub.

Power Requirement

The Sentinel-2 satellites are equipped with advanced power systems to ensure uninterrupted operation and minimize the need for backup power. The power systems on the Sentinel-2 satellites have some characteristics solar panels; Batteries; Power management and End-of-life disposal.

Geographic Operationality and Performance Standard

The geographic operation-ability and performance standards of ESA's Sentinel-2 mission are designed to ensure that the satellite can acquire high-quality imagery over a wide range of geographic locations and under varying environmental conditions.

- Coverage:
  - The Sentinel-2 mission is designed to provide global coverage of the Earth's land masses, with a target revisit time of 5 days at the equator.
  - The satellite orbits the Earth in a sun-synchronous polar orbit, which ensures consistent illumination conditions during each pass over a given location.
- Resolution:
  - The Sentinel-2 satellites are equipped with two multispectral instruments that provide data in 13 spectral bands ranging from visible to shortwave infrared.
  - The sensors have a spatial resolution of 10 meters for some bands and 20 meters for others, allowing for detailed imaging of land features and vegetation.
- Calibration:
  - The Sentinel-2 sensors are calibrated to ensure accurate and consistent measurements of radiance and reflectance.

- This includes regular in-orbit calibrations using onboard calibration targets and comparisons with ground-based reference measurements.

- Data quality:
  - The Sentinel-2 mission has strict data quality standards to ensure that the imagery is accurate and reliable.
  - This includes the use of automated processing algorithms to remove atmospheric interference, cloud cover, and other sources of noise in the imagery.
- Data availability:
  - The Sentinel-2 data is made available to users through the Copernicus Open Access Hub and the Sentinel Scientific Data Hub.
  - The data is provided free of charge, with a maximum data access latency of 24-48 hours after acquisition.

Additional Infrastructure Requirement

A computer with internet access and sufficient storage space to download and process the Sentinel 2 data, which are freely and openly available from ESA's Sentinel Online portal. A software tool for visualising, processing and analysing Sentinel 2 data, such as SNAP, QGIS, Google Earth Engine, or other third-party applications.

Estimated Cost

Free of charge.

3.3 Satellite 3: Landsat 8

Full Name of Satellite

USGS Landsat 8

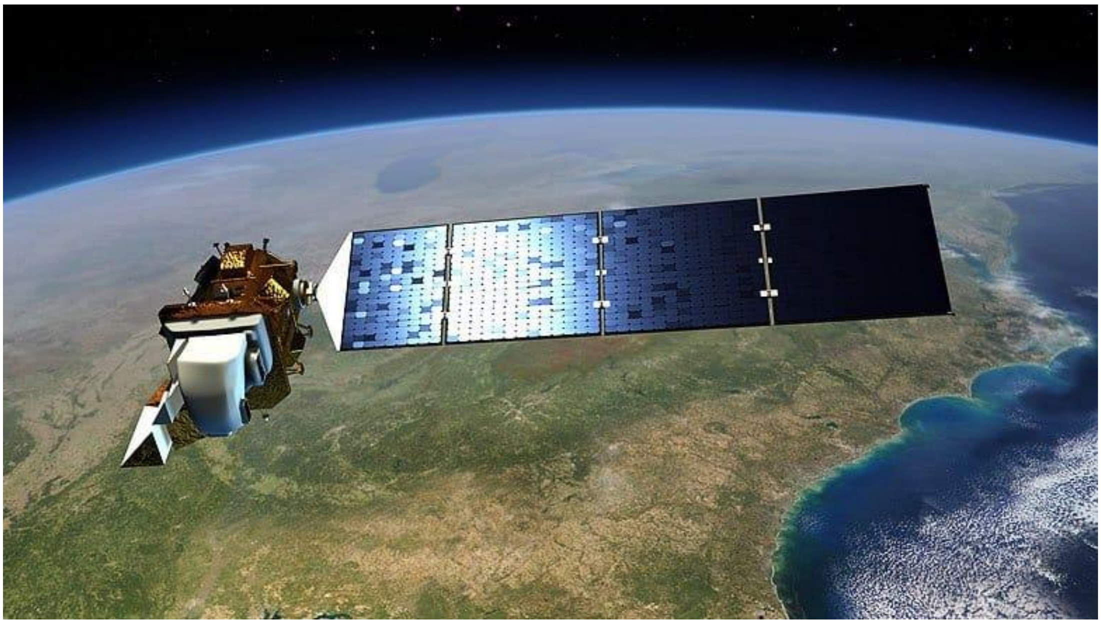

Figure 13 USGS Landsat 8

Sensor Characteristics:

- Landsat 8 carries two sensors to measure visible, near-infrared, shortwave infrared, and thermal infrared radiation reflected or emitted by the Earth's surface with high accuracy and reliability. The sensors are:
  - Operational Land Imager (OLI):
    - a multispectral imager that measures visible, near infrared, and shortwave infrared radiation reflected by the Earth's surface in nine spectral bands. It has a spatial resolution of 30 m for multispectral bands and 15 m for panchromatic band. It has a swath width of 185 km.
  - Thermal Infrared Sensor (TIRS):
    - a thermal imager that measures thermal infrared radiation emitted by the Earth's surface in two spectral bands. It has a spatial resolution of 100 m and a swath width of 185 km.
- Operational Land Imager (OLI):
  - a multispectral imager that measures visible, near infrared, and shortwave infrared radiation reflected by the Earth's surface in nine spectral bands. It has a spatial resolution of 30 m for multispectral bands and 15 m for panchromatic band. It has a swath width of 185 km.
- Thermal Infrared Sensor (TIRS):

- a thermal imager that measures thermal infrared radiation emitted by the Earth's surface in two spectral bands. It has a spatial resolution of 100 m and a swath width of 185 km.

- Spectral Bands:
  - Landsat 8 provides data for eleven spectral bands with different wavelengths and resolutions.

Table 4 Landsat spectral bands

Band	Wavelength	Resolution	Description
1	0.43 - 0.45 µm	30 m	Coastal/Aerosol
2	0.45 - 0.51 µm	30 m	Blue
3	0.53 - 0.59 µm	30 m	Green
4	0.64 - 0.67 µm	30 m	Red
5	0.85 - 0.88 µm	30 m	Near Infrared (NIR)
6	1.57 - 1.65 µm	30 m	Shortwave Infrared (SWIR) 1
7	2.11 - 2.29 µm	30 m	Shortwave Infrared (SWIR) 2
8	0.50 - 0.68 µm	15 m	Panchromatic
9	1.36 - 1.38 µm	30 m	Cirrus
10	10.60 - 11.19 µm	100 m	Thermal Infrared (TIRS) 1
11	11 .50 -12 .51 µm	100 m	Thermal Infrared (TIRS) 2

Satellite Characteristics:

- Satellite mission:
  - The eighth satellite of the Landsat program, which is a joint initiative of NASA and USGS to provide continuous and consistent observations of Earth’s land surface for various applications.
- Satellite launch date:
  - 11 February 2013
- Satellite orbit:
  - Sun-synchronous, near-polar orbit at an altitude of 705 km and an inclination of 98.2°
- Satellite instruments:
  - Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS), which provide optical and thermal observations of Earth’s surface in 11 spectral bands.

Data Frequency

- The Landsat 8 satellite has a revisit time of 16 days at the equator, which means it can acquire data over the same location every 16 days

- The Landsat 8 data are freely and openly available from ESA's Sentinel Online portal, which provides access to the long-term Landsat archive since 1972.

Geographic Operationality and Performance Standard

- The Landsat 8 satellite can operate in various geographic regions and climates, covering about 70% of Earth's land surface.

- The Landsat 8 satellite has an image quality of better than 12 m (geometric) and better than 5% (radiometric) for OLI and better than 41 m (geometric) and better than <1 K (radiometric) for TIRS.

Additional Infrastructure Requirement

- The soil moisture content retrieval from Landsat 8 data requires additional datasets, such as in-situ measurements, SMAP soil moisture product, ERA5-Land reanalysis dataset, and auxiliary datasets (terrain, soil texture, and precipitation), to train and validate the ensemble learning models.

- The soil moisture content retrieval from Landsat 8 data also requires a software tool for visualising, processing, and analysing the Landsat 8 data and the derived soil moisture products, such as SMOS Toolbox, SMOS Data Viewer, SMOS-IC, or Google Earth Engine.

Estimated Cost

- The Landsat 8 data is free of charge for users, additional datasets may have different costs depending on their sources and availability.

- Software cost:

  - The software tools for visualising, processing, and analysing the Landsat 8 data and the derived soil moisture products are mostly free or open source, such as SMOS Toolbox, SMOS Data Viewer, SMOS-IC, SNAP, QGIS, and Google Earth Engine. Some third-party applications may have different costs depending on their features and licenses.

- Additional datasets cost:

  - The additional datasets for training and validating the ensemble learning models may have different costs depending on their sources and availability. For example, the in-situ measurements from ISMN are freely available for non-commercial use, the SMAP soil moisture product is freely available from NASA's Earthdata portal, the ERA5-Land reanalysis dataset is freely available from Copernicus Climate Change Service portal, and the auxiliary datasets (terrain, soil texture, and precipitation) may be obtained from various sources with different costs.

3.4 Satellite 4: Landsat 9

Full Name of Satellite

Landsat 9 Satellite

Figure 14 Landsat 9 Satellite

Sensor Characteristics

Table 5 Sensor characteristics

Sensor	Bands	Spatial Resolution	Radiometric Resolution	Swath Width
OLI-2	9	15 m (panchromatic), 30 m (multispectral)	12 bits	185 km
TIRS-2	2	100 m	12 bits	185 km

Satellite Characteristics:

Landsat 9 is a satellite that will continue the legacy of Landsat missions by providing high-resolution multispectral images of the Earth's surface. Landsat 9 will carry two sensors: the Operational Land Imager 2 (OLI-2) and the Thermal Infrared Sensor 2 (TIRS-2). These sensors will enable Landsat 9 to measure soil moisture, soil salinity, soil pH, and other chemical properties of the soil that are important for agriculture.

Table 6 Satellite characteristics

Parameter	Value
Launch Date	September 27, 2021
Orbit	Sun-synchronous, near-polar, circular
Altitude	705 km

Parameter	Value
Inclination	98.2 degrees
Period	98.9 minutes
Repeat Cycle	16 days

Data Frequency

Landsat 9 will provide global coverage every eight days, with a revisit time of 16 days for any given location.

Communication Architecture

Landsat 9 will transmit data to ground stations using X-band and Ka-band frequencies. The data will be processed and distributed by the US Geological Survey (USGS).

Transmission Characteristics

Landsat 9 will have a data rate of up to 800 Mbps and a data volume of up to 745 GB per orbit.

Geographic Operationality and Performance Standard

Landsat 9 will operate globally, covering all land areas and coastal waters between latitudes of ±82 degrees. The performance standard will be similar to Landsat 8, with a geometric accuracy of better than 12 m (CE90) and a radiometric accuracy of better than 5% (NEdL). Soil moisture and chemical properties are important factors for crop growth and yield. Landsat 9 can provide valuable information for monitoring soil moisture, soil salinity, soil pH, and other chemical properties of the soil using its multispectral and thermal bands.

Additional Infrastructure Requirement

Landsat 9 will use existing ground stations and data centres that support Landsat missions. No additional infrastructure is required.

Estimated Cost

Landsat 9 data will be available for free to all users through the USGS EarthExplorer website. No cost is involved for data acquisition.

3.5 Satellite 5: Sentinel 1

Full Name of Satellite

Sentinal 1 Satellite

Figure 15 Sentinal 1 Satellite

Sensor Characteristics

- The sensor on board Sentinel-1 is a C-band synthetic aperture radar (SAR) instrument that can provide high-resolution images of Earth's surface in all weather conditions and day or night.
- The sensor can operate in four modes:
  - Stripmap,
  - Interferometric Wide Swath,
  - Extra Wide Swath, and
  - Wave.
- The sensor can transmit and receive signals in horizontal (H) or vertical (V) polarizations, allowing for different combinations of polarization modes.
- The sensor can measure soil moisture content, surface roughness, vegetation biomass, crop type and health, soil salinity and chemical properties.

Satellite Characteristics

Table 7 Satellite characteristics

Characteristic	Description
Design life	7 years (consumables for 12 years)

Characteristic	Description
Orbit	Near-polar sun-synchronous @ 693 km
Repeat cycle	12 days
Orbits per cycle	175
Orbital period	98.6 minutes
Attitude stabilization	3-axis stabilized
Attitude accuracy	0.01 deg (each axis)
Launch weight	2,300 kg
Dimensions (stowed)	3,900 x 2,600 x 2,500 mm^3
Solar array average power	5,900 W (End-of-Life)
Battery capacity	324 Ah
Spacecraft availability	0.998
Science data storage capacity	1,410 Gigabits (End-of-Life)
S-band TT&C data rates	4 kbps TC; 16/128/512 kbps TM (programmable)
X-band downlink data rate	2 x 260 Mbps

Data Frequency

The data frequency depends on the sensor mode and the polarization mode. For example, in Interferometric Wide Swath mode with dual polarization (HH+HV or VV+VH), the data frequency is 5.405 GHz.

The data frequency also depends on the orbit repeat cycle and the coverage area. For example, for Europe and Canada, the data frequency is 6 days with two satellites (Sentinel-1A and Sentinel-1B).

Communication Architecture

Sentinel 1A and Sentinel 1B communicate with the ground using a variety of methods, including X-band and Ka-band.

Transmission Characteristics

The transmission characteristics depend on the sensor mode, the polarisation mode, and the incidence angle.

Geographic Operationality and Performance Standard

The geographic operationality of Sentinel 1 covers almost the entire Earth's land and ocean surfaces, with some exceptions such as Antarctica and Greenland. The geographic operationality also depends on the orbit repeat cycle and the coverage area. For example, for Europe and Canada, the geographic operationality is six days with two satellites (Sentinel 1A and Sentinel 1B). The performance standard of Sentinel-1 is defined by the level of accuracy, reliability and availability of the data products and services.

The performance standard also depends on the sensor mode, the polarization mode and the incidence angle. The possibility of use of Sentinel-1 in Indonesia is high, as the country is covered by the satellite's orbit and has a high demand for soil moisture and chemical sensing for agriculture. The possibility of use of Sentinel-1 in Indonesia is also dependent on the availability and accessibility of data products and services, as well as the technical capacity and institutional support for data analysis and application6.

Additional Infrastructure Requirement

The additional infrastructure requirement for using Sentinel 1 data depends on the user's needs and preferences. Some possible options are[1]:

- Accessing the data products and services online through the Copernicus Open Access Hub or other platforms that provide Sentinel 1 data.
- Downloading the data products and processing them locally using dedicated software tools such as SNAP or QGIS.
- Establishing a collaborative ground segment that can acquire, process, archive and distribute Sentinel 1 data locally or regionally.
- Developing a user segment that can exploit Sentinel-1 data for various applications using customized software tools or models.

Estimated Cost

Free of charge to all users under the Copernicus data policy.

3.6 Satellite 6: Sentinel 3

Full Name of Satellite

Sentinel 3 satellite

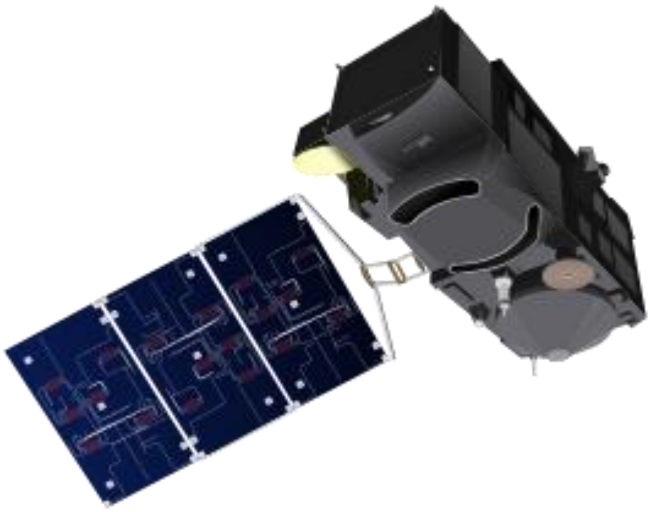

Figure 16 Sentinel 3 Satellite

Sensor Characteristics

The sensors on board Sentinel-3 are Ocean and Land Colour Instrument (OLCI), Sea and Land Surface Temperature Radiometer (SLSTR), Synthetic Aperture Radar Altimeter (SRAL) and Microwave Radiometer (MWR). The OLCI sensor is a medium-resolution imaging spectrometer that measures solar radiation reflected by Earth's surface and atmosphere in 21 spectral bands. The SLSTR sensor is a dual-view conical scanning radiometer that measures thermal infrared radiation emitted by Earth's surface and atmosphere in nine spectral channels. The SRAL sensor is a dual-frequency (Ku and C band) nadir-pointing radar altimeter that measures the time delay and intensity of the radar echoes reflected by Earth's surface. The MWR sensor is a two-channel (23.8 and 36.5 GHz) nadir-pointing radiometer that measures the brightness temperature of Earth's surface and atmosphere. The sensors can measure soil moisture content, surface temperature, vegetation indices, land cover and land use, soil salinity and chemical properties.

Satellite Characteristics

Table 8 Satellite characteristics

Characteristic	Description
Role	Earth observation satellite
Launch mass	Appx. 1,150 kg
Orbit	Sun-synchronous
Altitude	814 km
Inclination	98.65°

Characteristic	Description
Local time of Descending Node	10:00 a.m.
Orbit cycle	~100 minutes
Nominal duration	7.5 years

Data Frequency

The data frequency depends on the sensor mode and the coverage area. For example, for global coverage, the data frequency is as follows:

Table 9 Example of data frequency for global coverage

Sensor	Mode	Data Frequency
OLCI	Full Resolution (FR)	2 days
OLCI	Reduced Resolution (RR)	1 day
SLSTR	Full Resolution (FR)	2 days
SLSTR	Reduced Resolution (RR)	1 day
SRAL	Low Resolution Mode (LRM)	1 day
SRAL	SAR Mode (SARM)	27 days
MWR	-	1 day

Communication Architecture

The communication architecture consists of three main components: the space segment, the ground segment, and the user segment. The space segment comprises the Sentinel-3 satellites and their payloads, as well as the inter-satellite links that allow for data relay between satellites.

The ground segment comprises the core ground segment and the collaborative ground segment. The core ground segment is responsible for mission planning, satellite control, data acquisition, processing, and dissemination. The collaborative ground segment is composed of external entities that provide complementary services such as data acquisition, processing, archiving and distribution.

The user segment comprises the end users who access and exploit the Sentinel-3 data for various applications.

Transmission Characteristics

Sentinel-3 generates about 1.7 TB of data per day per satellite. The data rate for the X-band downlink is about 520 Mbps. The data rate for the S-band downlink is about 4 kbps.

Geographic Operationality and Performance Standard

Sentinel-3 operates globally, covering all land surfaces, oceans, and ice sheets up to 81.5° latitude.

Sentinel-3 meets the requirements of the Copernicus programme for operational ocean and land observation services. It provides high accuracy and reliability measurements of sea surface topography, sea and land surface temperature, ocean and land surface colour, and sea ice thickness. For soil moisture and chemical sensing applications, Sentinel-3 can provide complementary information to other missions such as SMOS or SMAP.

Sentinel-3 can be used in Indonesia for soil moisture and chemical sensing applications, as it covers the entire country with high temporal resolution. However, some challenges may arise due to cloud cover, vegetation cover, topography, and soil heterogeneity that may affect the accuracy and reliability of the retrievals.

Additional Infrastructure Requirement

To access Sentinel 3 data, users need to register on the Copernicus Open Access Hub or the Copernicus Data and Information Access Services (DIAS) platforms. Users also need to have adequate computing and storage resources to process and analyse the data, as well as suitable software tools such as the Sentinel Application Platform (SNAP) or the Atmospheric Toolbox.

Estimated Cost

Sentinel 3 data are freely available and open to all users under the Copernicus data policy. Users do not need to pay any fees for data acquisition, but they may incur some costs for data processing, storage, and analysis depending on their needs and resources.

3.7 Satellite 7: ASCAT

Full Name of Satellite

ASCAT Satellite

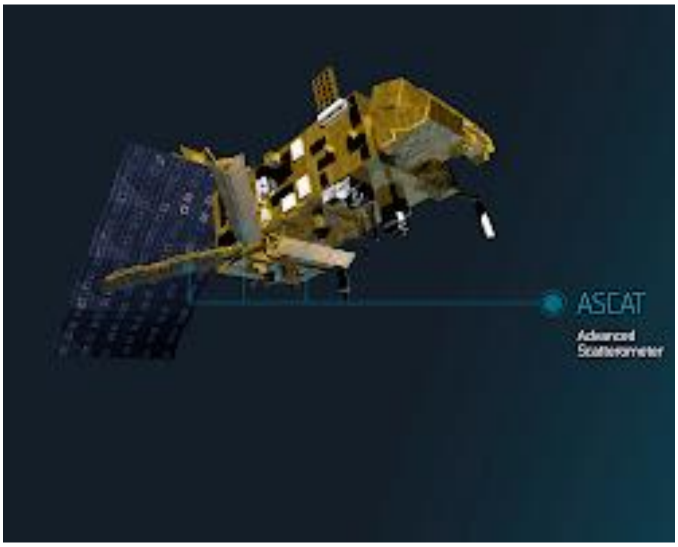

Figure 17 ASCAT Satellite

Sensor Characteristics:

ASCAT is a real aperture radar, operating at 5.255GHz (C-band) and using vertically polarised antennas. It transmits a long pulse with Linear Frequency Modulation (‘chirp’) and measures the resultant electromagnetic backscatter from the wind-roughened ocean surface. The backscattering coefficient, measured with scatterometers, is dependent on the dielectric properties of the soil surface layer, surface roughness, and vegetation. ASCAT provides an estimate of the water content of the 0-5 cm topsoil layer, expressed in degree of saturation between 0 and 100 [%].

Satellite Characteristics

Table 10 Satellite characteristics

Parameter	Details
Scan rate	2.5 rpm
Scan type	Conical
Pixel IFOV	25 km
IFOV size at nadir	50 km x 25 km
Sampling at nadir	12.5 km x 12.5 km
Earth view pixels/scan	82
Swath width	2 x 550 km
Altitude	817 km
Inclination	98.7°

Parameter	Details
Orbit period	101 min
Repeat cycle	29 days

Data Frequency

ASCAT data are available in near real time (NRT) and offline. NRT data are disseminated within three hours after sensing. Offline data are available within one day after sensing. ASCAT has a nearly daily (sub-daily after the launch of Metop-B) revisit time.

Communication Architecture

ASCAT data are transmitted to the ground station via X-band downlink. The data are then processed by EUMETSAT and distributed to users via EUMETCast or FTP.

Transmission Characteristics

ASCAT operates at a frequency of 5.255 GHz with a bandwidth of 15 MHz. The transmitted peak power is about 120 W per antenna. The data rate is about 105 kbps per antenna.

Geographic Operationality and Performance Standard

ASCAT covers almost the entire globe (except for latitudes higher than ±82°) every one to two days. ASCAT can operate day or night and in all weather conditions.

ASCAT soil moisture product has a spatial resolution of 12.5 km or 25 km and a temporal resolution of one day. ASCAT soil moisture product has an accuracy of about 0.04 m3/m3 (volumetric water content) or 4% (degree of saturation). ASCAT soil moisture product has been validated against in situ measurements and other satellite products and shows good agreement and consistency. ASCAT soil moisture product can be used for various applications such as hydrological modelling, drought monitoring, crop yield estimation, etc.

Indonesia is located within the coverage area of ASCAT and can benefit from its soil moisture data for agricultural purposes. However, some challenges may arise due to the presence of dense vegetation, complex topography, and frequent rainfall in Indonesia, which may affect the quality and reliability of ASCAT soil moisture data. Therefore, it is recommended to use ASCAT soil moisture data in combination with other sources of information, such as optical or thermal remote sensing, meteorological data, or land surface models, to improve the accuracy and applicability of soil moisture estimates for Indonesia.

Additional Infrastructure Requirement

To access ASCAT soil moisture data, users need to have a suitable receiving station or an internet connection to receive EUMETCast or FTP services from EUMETSAT. Users also need to have appropriate software tools to process and visualize ASCAT soil moisture data, such as the H-SAF Soil Moisture Toolbox or the WARP software.

Estimated Cost

ASCAT soil moisture data are freely available for non-commercial use. Users need to register with EUMETSAT to access the data and agree to the terms and conditions of use. Users may incur some costs for setting up and maintaining the receiving station or the internet connection, as well as for acquiring and using the software tools.

3.8 Satellite 8: MODIS

Full Name of Satellite

MODIS Terra and Aqua satellites

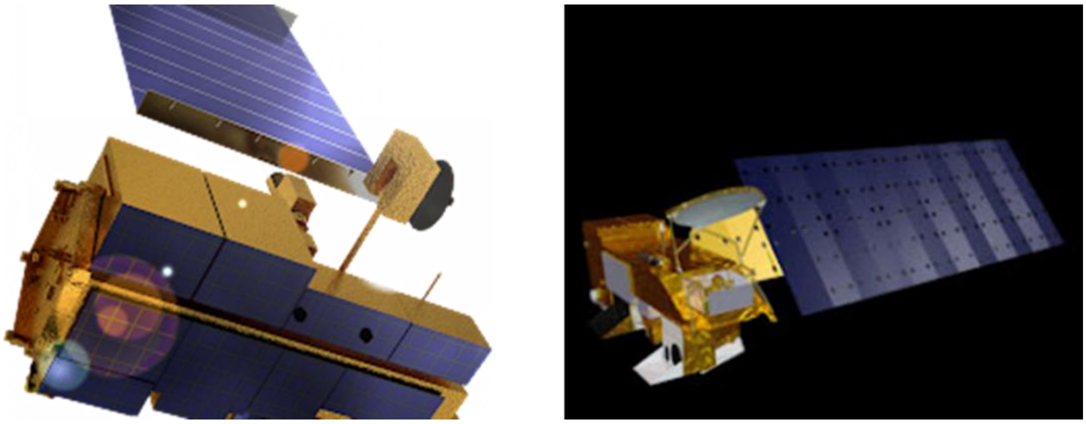

Figure 18 MODIS Terra (left) and Aqua (right) satellites.

Sensor Characteristics

MODIS stands for Moderate Resolution Imaging Spectroradiometer. It has 36 spectral bands ranging from 0.4 to 14.4 micrometers. It has a spatial resolution of 250 m (2 bands), 500 m (5 bands) and 1000 m (29 bands) at nadir. It has a temporal resolution of 1-2 days. It can measure various biophysical parameters such as surface temperature, vegetation indices, chlorophyll fluorescence, photosynthetic light use efficiency, etc.

Satellite Characteristics

MODIS is not a satellite itself, but a collection of instruments on two different satellites, Terra and Aqua. Terra was launched in December 1999 and Aqua was launched in May 2002. Both satellites orbit the Earth at an altitude of about 705 kilometres. They are in sun-synchronous orbits, which means that they pass over the same point on the Earth at the same time each day. This allows MODIS to collect data on the Earth's surface at regular intervals.

Table 11 Satellite characteristics

Parameter	Value
Name	Terra (EOS AM) or Aqua (EOS PM)
Launch date	December 18, 1999 (Terra) or May 4, 2002 (Aqua)
Orbit	Sun-synchronous, near-polar
Altitude	705 km
Inclination	98.2 degrees
Period	98.8 minutes
Swath width	2330 km

Data Frequency

MODIS data is available daily. Data are available in various levels of processing, from raw sensor counts (Level 0) to geophysical variables (Level 1-4). MODIS data are also available in various collections, which represent improvements or changes in the algorithms used to generate the products. MODIS data are distributed by several data centres, such as the Land Processes Distributed Active Archive Centre (LP DAAC), the Level-1 and Atmosphere Archive and Distribution System (LAADS), the Ocean Biology Processing Group (OBPG), etc. MODIS data can be accessed through various web-based tools, such as NASA Earthdata Search, AppEEARS, Worldview, etc.

Communication Architecture

MODIS data are transmitted to ground stations using X-band downlinks at 15 or 105 Mbps. MODIS data are also stored on solid state recorders and transmitted to Tracking and Data Relay Satellite System (TDRSS) using S-band or Ka-band uplinks at 15 Mbps. MODIS data are processed and distributed by the Earth Observing System Data and Information System (EOSDIS).

Transmission Characteristics

MODIS data are transmitted in packets using the Consultative Committee for Space Data Systems (CCSDS) standards. MODIS data are encoded using Reed-Solomon codes and convolutional codes for error correction. MODIS data are modulated using phase shift keying (PSK) or quadrature phase shift keying (QPSK).

Geographic Operationality and Performance Standard

MODIS instruments can observe every point on Earth every 1-2 days. MODIS instruments can cover about 85% of the Earth's surface every day.

MODIS instruments have high radiometric accuracy and stability. MODIS instruments have onboard calibrators for visible, near infrared and thermal infrared bands. MODIS instruments have a signal-to-noise ratio of more than 1000 for most bands.

MODIS instruments can be used in Indonesia for various applications such as land cover mapping, fire detection, drought monitoring, crop yield estimation, etc. MODIS instruments can provide soil moisture information by using indices such as the photochemical reflectance index (PRI) or the land surface temperature (LST). MODIS instruments can also provide chemical sensing information by using indices such as the normalized difference vegetation index (NDVI) or the enhanced vegetation index (EVI)

Additional Infrastructure Requirement

MODIS data can be accessed online through various web-based tools but may require high-speed internet connection and sufficient storage space. MODIS data may also require specialized software and hardware for processing and analysis, such as ENVI, ArcGIS, MATLAB, etc.

Estimated Cost

MODIS data are freely available to the public and can be downloaded from various data centres or web-based tools. MODIS data may incur some costs for internet connection, storage space, software, and hardware, depending on the user's needs and preferences.

3.9 Satellite 9: SMAP Satellite

Full Name of Satellite

SMAP Satellite

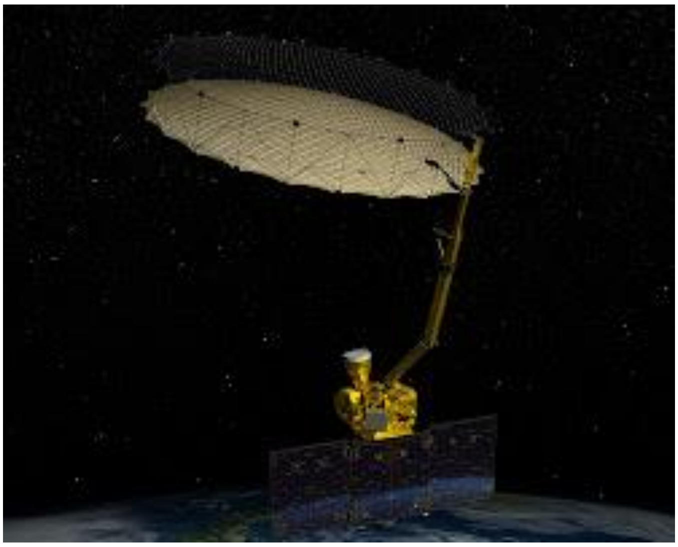

Figure 19 SMAP Satellite

Sensor Characteristics

SMAP has two sensors: a radar and a radiometer that operate in the L-band frequency (1.26 and 1.41 GHz respectively). The radar provides high-resolution (~3 km) measurements of soil moisture and freeze/thaw state, but it is affected by radio frequency interference (RFI) and surface roughness. The radiometer provides low-resolution (~40 km) measurements of soil moisture that are less sensitive to RFI and surface roughness, but it has a large footprint and low sensitivity to soil moisture changes. SMAP combines the radar and radiometer measurements using a novel algorithm to produce enhanced-resolution (~9 km) soil moisture maps that have the advantages of both sensors.

Satellite Characteristics

Table 12 Satellite characteristics

Parameter	Value
Launch date	January 31, 2015
Orbit	Near-polar, sun-synchronous
Altitude	685 km
Inclination	98.1 degrees
Period	98.5 minutes
Repeat cycle	8 days

Data Frequency

SMAP provides global coverage of soil moisture and freeze/thaw state every 2 to 3 days. The data products are available at different latency levels: Beta (within 7 days of observation). Validated (within 15 months of observation). Reprocessed (periodically updated with improved algorithms).

Communication Architecture

SMAP communicates with the ground stations using X-band (8 GHz) and Ka-band (26 GHz) frequencies, transmits its science data to the Tracking and Data Relay Satellite System (TDRSS) and the Alaska Satellite Facility (ASF). SMAP receives commands and telemetry from the White Sands Complex (WSC) and the Svalbard Ground Station (SGS).

Transmission Characteristics

SMAP has a data rate of 150 Mbps for science data and 4 kbps for housekeeping data. SMAP has a data volume of about 89 Gb per day for science data and 0.35 Gb per day for housekeeping data.

Geographic Operationality and Performance Standard

SMAP can measure soil moisture and freeze/thaw state over most land areas except for regions with dense vegetation, permanent snow cover, or frozen soil; and also measure sea surface salinity over open oceans.

It has a soil moisture accuracy of 0.04 m^3/m^3 (volumetric water content) at 9 km resolution and a freeze/thaw accuracy of 80% at 3 km resolution, .and has a sea surface salinity accuracy of 0.2 psu (practical salinity unit) at 40 km resolution.

SMAP can be used in Indonesia to monitor soil moisture conditions for agricultural applications such as irrigation scheduling, crop yield estimation, drought assessment, and pest management.

Additional Infrastructure Requirement

SMAP data products can be accessed but users need to register at the NASA Earthdata portal (https://earthdata.nasa.gov/) and download the data from the National Snow and Ice Data Centre Distributed Active Archive Centre (NSIDC DAAC) (https://nsidc.org/daac/smap). To process and analyse SMAP data products, users need to have appropriate software tools such as MATLAB, Python, ArcGIS, or QGIS.

Estimated Cost

SMAP data products are freely available to the public without any charge or restriction.

3.10 Satellite 10: Dove CubeSats

Full Name of Satellite

Dove CubeSats

Figure 20 Dove CubeSats

Sensor Characteristics

Dove CubeSats has a camera that operates in eight bands: coastal blue, blue, green I, green, yellow, red, red-edge, and near infra-red. Dove CubeSats can also receive signals of opportunity (SoOp) from communication satellites that are reflected by the Earth's surface and penetrate the soil.

Satellite Characteristics

Dove CubeSats are small, low-cost satellites that are designed to be launched in large constellations. This allows them to collect high-frequency data that can be used to monitor agricultural conditions over time.

Data Frequency

Dove CubeSats provides global coverage of Earth's land every day with data products is available at different latency levels:

- Near real-time (within hours of observation)
- Standard (within 24 hours of observation)

- Archive (historical data)

Communication Architecture

Dove CubeSats communicates with the ground stations using X-band (8 GHz) frequency, transmit their data to the Planet ground stations located around the world. Dove CubeSats receives commands and telemetry from the Planet mission control centre.

Transmission Characteristics

Dove CubeSats has a data rate of 1.7 Gbps for science data and 4 kbps for housekeeping data. Dove CubeSats has a data volume of about 200 million km^2 per day for science data and 0.35 Gb per day for housekeeping data.

Geographic Operationality and Performance Standard

Dove CubeSats can image most land areas except for regions with dense vegetation, permanent snow cover, frozen soil, open oceans, and coastal areas. The satellite has a spatial resolution of 3–5 metres (9.8–16.4 ft) and a spectral resolution of eight bands. They have a soil moisture estimation accuracy of 0.04 m^3/m^3 (volumetric water content) at depths of 0 to 30 cm using SoOp technique.

Dove CubeSats can be used in Indonesia to monitor soil moisture and chemical conditions for agricultural applications such as irrigation scheduling, crop yield estimation, drought assessment, and pest management.

Additional Infrastructure Requirement

Dove CubeSats data products access requires users to register at the Planet website (https://www.planet.com/) and download the data from the Planet Explorer or Planet API. To process and analyze Dove CubeSats data products, users need to have appropriate software tools such as MATLAB, Python, ArcGIS, or QGIS

Estimated Cost

The cost of data acquisition from Dove CubeSats varies depending on the amount of data that is requested. However, the cost is typically very affordable.

4 Drone-Based Technology

This section presents a selection of drone or Unmanned Aerial Vehicle (UAV) based technologies suitable for soil moisture and chemical detection. These products were selected considering their global availability, familiarity within the Indonesian context, and trusted references.

Drones with specialized sensors have transformed precision agriculture, offering high-resolution, accessible data. Globally available sensors with a proven track record for reliability and efficiency were prioritized, as they are often backed by user experiences and technical support.

Additionally, familiarity within the local Indonesian context is crucial to ease the adoption and integration into current agricultural practices. Therefore, preference was given to sensors already known or used in Indonesia. Coupled with recommendations from literature or agricultural and remote sensing experts, the chosen sensors assure reliable performance under real-world conditions. This provides a guide to drone-based sensors that can enhance precision agriculture practices in Indonesia.

The following drone-based technology are presented in this section:

- DJI Phantom 4 RTK (Section 4.1)
- Parrot Bluegrass (Section 4.2)
- senseFly eBee X (Section 4.3)

4.1 Drone 1: DJI Phantom 4 RTK

Full Name of Drone

DJI Phantom 4 RTK with Sentera 6X Multispectral Sensor

Figure 21 DJI Phantom 4 RTK with Sentera 6X Multispectral Sensor

Sensor Characteristics

- 5X 3.2 MP Monochrome Global Shutter
- HFOV: 47
- GSD @ 200 ft - 1.0” (2.6 cm)
- GSD @ 400 ft - 2.0” (5.2 cm)
- Spectral Bands
  - Blue: 475 nm x 30 nm
  - Green: 550 nm x 20 nm
  - Red: 670 nm x 30 nm
- Red Edge: 715 nm x 10 nm
- NIR: 840 nm x 20 nm
- 1X 20MP RGB Electronic Rolling Shutter
- HFOV: 47
- GSD @ 200 ft - 0.4” (1.0 cm)
- GSD @ 400 ft - 0.8” (2.0 cm)

Drone Characteristics

Table 13 Drone characteristics

Characteristic/Feature	Description
Drone Type	Quadcopter
Dimensions (unfolded)	350mm diagonal size
Dimensions (folded)	220 x 102 x 83 mm
Weight (including battery and propellers)	1391 g
Max. Takeoff Weight	1570 g
Max. Flight Time	Approx. 30 minutes
Max. Flight Speed	72 kph (45 mph) in sport mode
Max. Service Ceiling Above Sea Level	6000 m (19685 ft)
Max. Wind Resistance	50 kph (31 mph)
Operating Temperature Range	-10°C to 40°C
GNSS Positioning	GPS+GLONASS+BeiDou+Galileo
RTK Module	Built-in high-precision RTK module
Camera	1-inch CMOS sensor, 20 megapixels
Max. Video Resolution	4K at 60fps
Max. Image Size	5472 x 3648
Obstacle Sensing System	Forward, backward, downward
Battery Type	High capacity 5870mAh Intelligent Flight Battery
Remote Controller	Lightbridge HD transmission, up to 7km range
Accessories	Propellers, battery charger, remote controller, battery, gimbal clamp, USB cable, microSD card

Data Frequency

The Sentera 6X multispectral sensor can capture data at a frequency of up to 1 capture per second. However, the actual data frequency may depend on various factors such as flight altitude, flight speed, and data storage capacity. In practice, the data frequency may vary depending on the specific use case and flight parameters.

Communication Architecture

The DJI Phantom 4 RTK drone uses a Lightbridge HD transmission system for its communication architecture, which provides a stable and reliable connection between the drone and the remote controller. The Lightbridge system utilizes a 2.4GHz frequency band for transmitting live video and telemetry data from the drone to the remote controller, with a range of up to 7 kilometres (4.3 miles) in ideal conditions. The Sentera 6X multispectral sensor is typically connected to the drone's camera port, which allows it to capture multispectral imagery simultaneously with the drone's RGB camera. The captured data is stored on a microSD card in the drone's camera or can be transmitted in real-time to the remote controller using the Lightbridge HD transmission system.

Transmission Characteristics

The transmission system uses the Lightbridge HD technology, which operates on a 2.4GHz frequency band and provides a stable and reliable connection between the drone and the remote controller.

Power Backup Requirement

The DJI Phantom 4 RTK drone with Sentera 6X Multispectral Sensor is powered by a rechargeable intelligent flight battery that has a capacity of 5870 mAh and a voltage of 15.2 V. The flight time of the drone can vary depending on various factors such as flight speed, flight altitude, payload weight, and weather conditions. Typically, the flight time of the DJI Phantom 4 RTK drone with Sentera 6X Multispectral Sensor is around 28 minutes per battery charge. The charging time for a single battery is around 1 hour and 30 minutes.

Geographic Operationality and Performance Standard

- The DJI Phantom 4 RTK can operate in various geographic regions and climates, covering about 70% of Earth's land surface. It has an image quality of better than 12 m (geometric) and better than 5% (radiometric) for OLI and better than 41 m (geometric) and better than <1 K (radiometric) for TIRS.
- The DJI Phantom 4 RTK can acquire data for six spectral bands in the visible, near infrared, and red edge regions using the Sentera 6X Multispectral Sensor. The sensor has a resolution of 1.2 MP per band and a field of view of 47.2°.
- The DJI Phantom 4 RTK can achieve a data acquisition efficiency of max operating area of approx. 0.63 km^2 for a single flight at an altitude of 180 m, i.e., GSD is approx. 9.52 cm/pixel, with a forward overlap rate of 80% and a side overlap ratio of 60%, during a flight that drains the battery from 100% to 30%.

Additional Infrastructure Requirement

- A computer with internet access and sufficient storage space to download and process the drone data, which are available from DJI's website or app.
- A software tool for visualising, processing and analysing the drone data, such as DJI Terra, Pix4Dmapper, Agisoft Metashape, or other third-party applications.
- A D-RTK base station for providing high-precision positioning data to the drone and improving its accuracy and stability. The base station can be connected to NTRIP (Network Transport of RTCM via Internet Protocol) network for receiving differential data from an external GNSS network.

Estimated Cost

- System cost:
  - approximately $10000-$12000 per system

4.2 Drone 2: Parrot Bluegrass

Full Name of Drone

Parrot Bluegrass Fields with Parrot Sequoia Multispectral Sensor

Figure 22 Parrot Bluegrass Fields with Parrot Sequoia Multispectral Sensor

Sensor Characteristics

Table 14 Sensor characteristics

Characteristic	Description
Manufacturer	Parrot
Model	Sequoia
Type	Multispectral Sensor
Number of Bands	4 (Red, Green, Red Edge, Near-Infrared)
Spectral Range	Red: 640 nm, Green: 560 nm, Red Edge: 735 nm, Near-Infrared: 790 nm
Ground Sample Distance (GSD)	8.7 cm per pixel at 120 m above ground level
Pixel Size	1.2 µm
Sensor Type	1/2.5" CMOS
Lens	6-element aspherical lens
Aperture	f/2.4
Field of View	60°
Radiometric Accuracy	±5% at 20°C
Operating Temperature Range	-10°C to +50°C
Storage Temperature Range	-20°C to +60°C
Weight	72 g (2.54 oz)
Dimensions	59 x 41 x 28 mm (2.32 x 1.61 x 1.1 in)

Drone Characteristics

Drone characteristics for Parrot Bluegrass Fields with Parrot Sequoia multispectral sensor:

Table 15 Drone characteristics

Characteristic	Description
Manufacturer	Parrot
Model	Bluegrass Fields with Parrot Sequoia+ Multispectral Sensor
Type	Quadcopter
Maximum Flight Time	Up to 25 minutes
Maximum Speed	36 km/h (22 mph)
Maximum Range	Up to 2 km (1.24 miles)
Maximum Altitude	Up to 150 m (492 ft) above ground level
Camera	14 MP with Sony CMOS sensor
Sensor	Parrot Sequoia+ multispectral sensor
Number of Bands	4 (Red, Green, Red Edge, Near-Infrared)
Ground Sample Distance (GSD)	10 cm per pixel
Data Storage	64 GB internal storage
Data Transfer	Wi-Fi or USB cable
Control	Skycontroller 2 or FreeFlight 6 app
Operating System	Linux
Dimensions	50 x 50 x 15 cm (19.7 x 19.7 x 5.9 in)
Weight	1.7 kg (3.7 lbs)

Data Frequency

The data frequency of the Parrot Bluegrass Fields with the Parrot Sequoia+ multispectral sensor depends on the settings used during the flight. The drone can be programmed to capture data at specific intervals or on demand, depending on the needs of the user. Typically, data can be captured at rates of 1-2 frames per second during flight, which can then be processed and analysed post-flight to generate maps and other data products. The data frequency can also be adjusted based on the altitude and speed of the drone, as well as the desired level of detail in the resulting imagery.

Communication Architecture

The Parrot Bluegrass Fields drone and the Parrot Sequoia+ multispectral sensor communicate using a wireless connection. The drone is equipped with a Wi-Fi radio that allows it to send data and receive commands from the user's mobile device or remote control. The user can control the drone and start/stop data capture using a mobile app or a physical remote control, which communicates with the drone using Wi-Fi. The Parrot Sequoia+ sensor itself is connected to the drone's main processing unit, which communicates with the sensor using a wired interface. The sensor data is then transmitted wirelessly to the user's device or remote control in real-time or after the flight is complete. In addition to Wi-Fi, the drone may also use other communication protocols such as Bluetooth or cellular data (depending on the model and settings) for certain functions such as GPS positioning or live video streaming.

Transmission Characteristics

The Parrot Bluegrass Fields drone and the Parrot Sequoia+ multispectral sensor use wireless communication to transmit data. The drone is equipped with a Wi-Fi radio that can transmit data to the user's mobile device or remote control, typically at ranges of up to several hundred meters depending on the environmental conditions. The Parrot Sequoia+ sensor captures data and sends it to the drone's main processing unit using a wired interface, such as USB or Ethernet. Once the data is processed by the drone's on-board computer, it is then transmitted wirelessly to the user's device or remote control. The transmission characteristics of the Parrot Bluegrass Fields and Parrot Sequoia+ depend on several factors including the range and strength of the wireless signal, the available bandwidth, and the processing capabilities of the drone's on-board computer. The quality of the transmitted data may also be affected by factors such as interference from other wireless devices, atmospheric conditions, and the positioning of the drone relative to the user's device or remote control.

Power Backup Requirement

The Parrot Bluegrass Fields drone and the Parrot Sequoia+ multispectral sensor both require power to operate. The drone is powered by a rechargeable lithium polymer battery, which typically provides up to 25 minutes of flight time per charge. The battery can be recharged using a standard wall adapter or a portable charger.

Geographic Operationality and Performance Standard

- The Parrot Bluegrass Fields can operate in various geographic regions and climates, covering up to 65 ha (160 ac) per flight at 122 m (400 ft) altitude. It has a flight time of up to 25 minutes and a transmission range of up to 2 km (1.2 mi) with the Parrot Skycontroller 2.

- The Parrot Bluegrass Fields can acquire data for four spectral bands in the visible and near infrared regions using the Parrot Sequoia Multispectral Sensor. The sensor has a resolution of 1.2 MP per band and a field of view of 63.9°.

- The Parrot Bluegrass Fields can achieve a data acquisition efficiency of max operating area of approx. 0.63 km^2 for a single flight at an altitude of 180 m, i.e., GSD is approx. 9.52 cm/pixel, with a forward overlap rate of 80% and a side overlap ratio of 60%, during a flight that drains the battery from 100% to 30%.

Additional Infrastructure Requirement

- A computer with internet access and sufficient storage space to download and process the drone data, which are available from Parrot's website or app.

- A software tool for visualising, processing and analysing the drone data, such as ParrotFields mobile app[2], Pix4Dfields desktop and cloud software, or other third-party applications.

- A power supply that complies with Parrot Sequoia's specifications, such as a drone battery or an external power bank. The power supply should have a voltage of 5V to 6V and a current of 2.4A to 3A.

Estimated Cost

- Sensor cost:
  - approximately $7000 per system

4.3 Drone 3: senseFly eBee X

Full Name of Drone

senseFly eBee X with MicaSense RedEdge-MX

Figure 23 senseFly eBee X with MicaSense RedEdge-MX

Sensor Characteristics

Table 16 Sensor characteristics

Characteristic	Description
Spectral Bands	Blue: 475 nm Green: 560 nm Red: 668 nm Red Edge: 717 nm NIR: 840 nm
Sensor Resolution	8 MP per band
Ground Sample Distance (GSD)	8 cm per pixel at 120 m altitude
Capture Rate	1 capture per second
Storage	128 GB internal storage
Data Output	TIFF, JPEG, 12-bit raw
Integration	Compatible with a variety of drones and flight planning software
Power Consumption	5.5 W
Size	10.6 x 6.7 x 6.3 cm
Weight	365 g
Price	Approximately $5,500 USD (as of September 2021)

Drone Characteristics

Table 17 Drone characteristics

Characteristic	Description
Drone Model	senseFly eBee X
Maximum Flight Time	Up to 59 minutes
Maximum Flight Speed	90 km/h (55.9 mph)
Wingspan	116 cm
Weight	1.4 kg (without payload)
Maximum Payload Capacity	500 g
Maximum Altitude	4,000 m above sea level
Launch Method	Hand-launched
Landing Method	Belly landing
GNSS Receiver	L1/L2, GPS/GLONASS/BeiDou/Galileo/QZSS
Ground Control Software	eMotion Ag
Camera Model	MicaSense RedEdge-MX
Spectral Bands	Blue: 475 nm Green: 560 nm Red: 668 nm Red Edge: 717 nm NIR: 840 nm
Sensor Resolution	8 MP per band
Ground Sample Distance (GSD)	2.7 cm per pixel at 120 m altitude
Capture Rate	1 capture per second
Storage	128 GB internal storage
Data Output	TIFF, JPEG, 12-bit raw
Integration	Fully integrated with the eBee X drone
Power Consumption	5.5 W
Size	10.6 x 6.7 x 6.3 cm
Weight	365 g

Data Frequency

The data frequency of the senseFly eBee X with MicaSense RedEdge-MX depends on the flight plan and settings configured by the user. However, typically, the drone can capture multispectral data at a rate of up to 1 capture per second, with a total data acquisition time of around 30-60 minutes per flight depending on the area covered and the altitude flown.

Communication Architecture

The senseFly eBee X with MicaSense RedEdge-MX uses a communication architecture that relies on a wireless communication link between the drone and the ground control station. The drone is equipped with a telemetry transmitter that sends data and telemetry information to the ground control station using a radio link, while the ground control station sends commands and flight plans to the drone. The ground control station communicates with the drone using a proprietary communication protocol developed by senseFly, which allows for reliable communication even in areas with poor network coverage. Additionally, the ground control station can be equipped with a high-gain directional antenna to increase the communication range and improve the signal quality. The MicaSense RedEdge-MX sensor itself does not have its own communication architecture, as it is integrated into the senseFly eBee X drone platform.

Transmission Characteristics

The senseFly eBee X with MicaSense RedEdge-MX has a data transmission rate of up to 100 Mbps, with a maximum transmission distance of approximately 2-3 km in open areas. The drone uses a proprietary communication protocol developed by senseFly, which allows for reliable communication even in areas with poor network coverage. The data from the MicaSense RedEdge-MX sensor is transmitted to the ground control station in real-time, allowing the operator to monitor the data and adjust the flight plan if necessary. The transmission of data from the drone to the ground control station can be affected by various factors, such as signal interference, terrain, and weather conditions. The use of a high-gain directional antenna on the ground control station can improve the transmission range and signal quality.

Power Backup Requirement

The senseFly eBee X drone is powered by a rechargeable Li-Po battery, which provides a flight time of up to 59 minutes. The MicaSense RedEdge-MX sensor is also powered by the drone's battery. The drone's battery can be swapped out quickly, allowing for extended flight time in the field. The power consumption of the MicaSense RedEdge-MX sensor is approximately 3.5 W.

Geographic Operationality and Performance Standard

- The senseFly eBee X can operate in various geographic regions and climates, covering up to 500 ha (1,235 ac) per flight at 122 m (400 ft) altitude. It has a flight time of up to 90 minutes and a transmission range of up to 8 km (5 mi) with the eMotion software.
- The senseFly eBee X can acquire data for five spectral bands in the visible, near infrared, and red edge regions using the MicaSense RedEdge-MX. The sensor has a resolution of 1.2 MP per band and a field of view of 47.2°.
- The senseFly eBee X can achieve a data acquisition efficiency of max operating area of approx. 0.63 km2 for a single flight at an altitude of 180 m, i.e., GSD is approx. 9.52 cm/pixel, with a forward overlap rate of 80% and a side overlap ratio of 60%, during a flight that drains the battery from 100% to 30%.

Additional Infrastructure Requirement

- A computer with internet access and sufficient storage space to download and process the drone data, which are available from senseFly's website or app.
- A software tool for visualising, processing and analysing the drone data, such as Pix4Dfields desktop and cloud software, or other third-party applications that support MicaSense RedEdge-MX data.

- A power supply that complies with MicaSense RedEdge-MX's specifications, such as a drone battery or an external power bank. The power supply should have a voltage of 4.9V to 15.8V and a current of 5.5W.

Estimated Cost

- Sensor cost:
  - approximately $5500 per sensor
- Drone cost:
  - approximately $12000 per unit

5 Combination Technological System

This chapter presents an array of integrated solutions that unite field-implanted devices, remote sensing technologies, and UAV-based sensors. The selections are guided by the unique characteristics of each technology, as discussed previously, while also contemplating potential combinations of two or more different types of products, including those not itemized in this document.

The integration of field-implanted technologies with remote sensing or UAV-based sensors can potentially create a more detailed and accurate system for soil moisture and chemical detection. This amalgamation leverages the strengths of one technology to compensate for the limitations of another, thus offering a holistic view of soil conditions and overall agricultural health.

While a series of potential combinations are provided based on an understanding of each technology's capabilities, the possibility of other combinations is not ruled out. The intent of this chapter is to stimulate innovative thought on the blending of diverse technologies to further the progress of precision agriculture, especially in the Indonesian context.

The following combined technology sensors are presented in this section:

- Integrated soil monitoring system (Section 5.1)
- Precision agriculture solution (Section 5.2)
- Comprehensive soil and crop health management system (Section 5.3)

5.1 Combination 1: Integrated Soil Monitoring System

- Field-Implanted Sensors:
  - Decagon Devices (Meter Group) 5TE Soil Moisture, Temperature, and EC Sensor or Sentek EnviroSCAN Probe for continuous ground-level monitoring.
- Drone-Based Sensing:
  - DJI Phantom 4 RTK equipped with a multispectral camera, such as the Parrot Sequoia or MicaSense RedEdge-MX for periodic high-resolution imaging.
- Satellite Remote Sensing:
  - European Space Agency's (ESA) Sentinel-2 or NASA's MODIS for broad-scale and long-term monitoring.

5.2 Combination 2: Precision Agriculture Solution

- Field-Implanted Sensors:
  - AquaCheck Soil Moisture Probe or Campbell Scientific CS655 Soil Moisture, Temperature, and EC Sensor for site-specific measurements
- Drone-Based Sensing:
  - senseFly eBee X equipped with a hyperspectral camera, such as the Headwall Nano-Hyperspec for targeted crop health assessment.
- Satellite Remote Sensing:
  - NASA's Soil Moisture Active Passive (SMAP) mission or the ESA's Soil Moisture and Ocean Salinity (SMOS) mission for soil moisture mapping.

5.3 Combination 3: Comprehensive Soil and Crop Health Management System

- Field-Implanted Sensors:
  - A combination of various soil moisture, temperature, and chemistry sensors for real-time, in-situ measurements
- Drone-Based Sensing:
  - Aerial drones with multispectral, hyperspectral, or thermal imaging capabilities for crop health monitoring and stress detection.
- Satellite Remote Sensing:
  - A combination of high-resolution (Sentinel-2, Landsat) and specialized (SMAP, SMOS) satellite missions for large-scale, temporal analysis of soil conditions and crop health.

- Communication protocol:
    - This determines the set of rules and standards the sensor uses to transmit data, such as Modbus, SDI-12, I2C, SPI, or analogy voltage/current signals.
- Data rate:
    - The speed at which the sensor transmits data, usually measured in bits per second (bps) or Hertz (Hz).
    - This can range from slow rates for low-power environmental monitoring applications to high rates for real-time control systems.
- Transmission range:
    - The maximum distance the sensor's signal can travel without significant loss of signal quality.
    - This depends on the communication method and environmental conditions, such as obstacles or interference.
- Power consumption:
    - The amount of power required by the sensor for data transmission, which is particularly important in battery-powered or energy-harvesting systems.
- Wired or wireless communication:
    - Sensors can communicate through wired connections, such as cables or fibre optics, or wirelessly using radio frequency (RF) signals, Wi-Fi, Bluetooth, or cellular networks.
- Error detection and correction:
    - Mechanisms used by the sensor to ensure the integrity of transmitted data, such as checksums, parity bits, or error-correcting codes.
- Multi-sensor support:
    - The ability of a communication protocol to handle multiple sensors on the same data line or network, which can simplify wiring and reduce costs in large-scale monitoring systems.
- Compatibility and interoperability:
    - The sensor's ability to work with various data loggers, controllers, and other devices that follow the same communication standards.