

APPENDICES

APPENDIX A

Summary of Specifications for Sukabumi Region, West Java Province, Indonesia

A Summary of Specifications for Sukabumi Region, West Java Province, Indonesia

The applicability of soil moisture and chemistry sensing systems for Sukabumi region, West Java, Indonesia depends on various factors, including the size and type of farms, the resources available, and the local agricultural practices. Here, we provide a general overview of how different systems may be suitable for this region:

- **Field-Implanted Sensors:** These sensors can be used for small to medium-sized farms in the Sukabumi region to provide accurate soil moisture and chemistry data. They are particularly helpful for optimizing irrigation and fertilizer use. Field-implanted sensors can also be beneficial for crops that require close monitoring, such as high-value or sensitive crops.
- **Satellite Remote Sensing:** This method can be used for large-scale agricultural operations and regional planning in Sukabumi. Satellite remote sensing data can support decision-making regarding water resources management, assessing crop health, and monitoring land use changes. However, it may not provide the same level of accuracy and resolution as other sensing methods.
- **Drone-Based Systems:** Drones can be employed for precision agriculture in the Sukabumi region, particularly for high-value crops or monitoring specific areas of interest in the field. Drone-based systems can help identify areas requiring targeted interventions, such as pest control, irrigation adjustments, or additional fertilization. They are also useful for mapping and monitoring the overall health of crops.
- **Integrated Systems:** An integrated approach combining different sensing systems can be beneficial for advanced precision agriculture management in the Sukabumi region. By leveraging the strengths of multiple systems, such as high-resolution drone imagery and accurate field-implanted sensor data, farmers can make more informed decisions to optimize crop productivity and resource use.

When selecting a suitable sensing system for the Sukabumi region, West Java, Indonesia, it is crucial to consider the specific agricultural requirements, available resources, and the local environment. Collaboration with local agricultural authorities, research institutions, and other stakeholders can also support the effective implementation of these technologies in the region.

For the Sukabumi region in West Java, Indonesia, particularly for food production crops, the following specific types of sensors could be employed to enhance agricultural management practices:

- **Soil Moisture Sensors:**
 - **Capacitive Soil Moisture Sensors:** These sensors measure the dielectric permittivity of the soil, which is related to soil moisture content. Capacitive sensors are known for their accuracy and long-term stability.
 - **Time Domain Reflectometry (TDR) sensors:** TDR sensors measure the time it takes for an electromagnetic pulse to travel through the soil and reflect back. They provide accurate and reliable soil moisture measurements.
- **Soil Chemistry Sensors:**

- Ion-Selective Electrodes: These electrodes can be used to measure specific ions in the soil, such as nitrate, potassium, or phosphate. This information can be helpful for optimizing fertilizer application.
- pH sensors: Monitoring soil pH is crucial for nutrient availability and overall crop health. A pH sensor can help farmers manage soil acidity and alkalinity to maximize nutrient uptake by plants.
- Plant Health Sensors:
 - Normalized Difference Vegetation Index (NDVI) sensors: NDVI sensors measure the reflectance of visible and near-infrared light to assess plant health and growth. These sensors can be mounted on drones or handheld devices to monitor crop health and identify potential issues early on.
 - Thermal Infrared (TIR) sensors: TIR sensors can detect the temperature of plant canopies, which is related to plant water stress. These sensors can be used to optimize irrigation scheduling and reduce water wastage.
- Weather Sensors:
 - Rain gauge: A rain gauge measures the amount of precipitation, providing essential information for irrigation management.
 - Temperature and humidity sensors: These sensors can help monitor the microclimate within the crop canopy, informing decisions related to pest and disease management, as well as crop-specific growth stages.

When selecting specific sensor types for food production crops in the Sukabumi region, consider factors such as local soil types, climate, predominant crops, and available resources. Collaborate with local agricultural experts and institutions to tailor the choice of sensors to the unique needs of the region.

A combined system utilizing drones and remote sensing can provide valuable, high-resolution data to monitor and manage food production crops in the Sukabumi region of West Java, Indonesia. Below is a suggested approach:

- Drone-based Sensors:
 - Multispectral cameras: These cameras capture multiple wavelengths of light, allowing for the assessment of plant health (NDVI), water stress, and nutrient deficiencies. Multispectral cameras mounted on drones enable more frequent and precise data collection at a higher spatial resolution than satellite-based remote sensing.
 - Thermal infrared (TIR) cameras: Drone-mounted TIR cameras can measure canopy temperature, providing insight into plant water stress and helping optimize irrigation scheduling.
- Satellite Remote Sensing:
 - Optical remote sensing: Satellites such as Sentinel-2 and Landsat provide multispectral images, capturing information about vegetation health, soil moisture, and surface temperature. While the spatial resolution is lower than drone-based imagery, these satellites offer broader coverage and regular data acquisition.
 - Synthetic Aperture Radar (SAR): SAR satellites, like Sentinel-1, can penetrate clouds and acquire data at night, providing information about soil moisture and vegetation structure. SAR data can complement optical data to provide a more complete understanding of crop conditions.

Data Integration and Analysis: Combine the high-resolution drone imagery with the broader coverage of satellite remote sensing to create a comprehensive and accurate view of the agricultural landscape. Utilize data fusion techniques to merge different types of remote sensing data and employ machine learning algorithms to identify patterns and trends.

Decision Support System (DSS): Develop a DSS that integrates drone and satellite-derived data with insitu measurements from ground-based sensors. The DSS should provide actionable insights to farmers, such as optimized irrigation schedules, nutrient management recommendations, and early warnings for pest and disease outbreaks.

Communication and Training: Ensure that farmers have access to the data and insights generated by the integrated drone and remote sensing system. This may involve developing a user-friendly interface, providing training on data interpretation and decision-making, and offering ongoing support to maximize the benefits of the system for food production in the Sukabumi region.

APPENDIX B

Examples of Products Available for Application in the Field

B Examples of Products Available for Application in the Field

Examples of products or technologies that have been applied in the field of soil moisture and chemistry monitoring:

- Decagon Devices (now METER Group) offers various soil moisture sensors, including the EC-5, 10HS, 5TE, and GS3 models. These sensors measure volumetric water content, soil temperature, and electrical conductivity, providing a comprehensive understanding of soil conditions for agricultural and environmental applications. Website: <https://www.metergroup.com/environment/products/?application=3>
- TDR-based soil moisture sensors, such as the TRIME-PICO64 by IMKO Micromodultechnik, have been utilized to measure soil moisture content with high accuracy and precision. The portable device allows for non-destructive, in-situ measurements and provides a user-friendly interface for data collection and analysis. Website: <https://www.imko.de/en/products/trime-pico-64.html>
- The SoilCares Lab-in-a-Box (now AgroCares) is an innovative soil testing technology that combines spectroscopy with data analysis algorithms to deliver accurate soil nutrient data within a matter of hours. This portable soil laboratory helps farmers and agricultural advisors to make better-informed decisions regarding nutrient management and crop production. Website: <https://www.agrocares.com/en/products/scanner/>
- Parrot Sequoia is a multispectral sensor designed specifically for agricultural drones. It captures data across four spectral bands (green, red, red edge, and near-infrared), allowing for in-depth analysis of vegetation health and stress levels. This information can help farmers monitor crop growth and make informed decisions about fertilization, irrigation, and pest management. Website: <https://www.parrot.com/business-solutions-us/parrot-professional/parrot-sequoia>
- Satellites such as the European Space Agency's (ESA) Sentinel-1 and Sentinel-2 missions provide soil moisture data and imagery at high spatial and temporal resolutions. These satellites are part of the Copernicus program, which aims to provide comprehensive environmental monitoring data for various applications, including agriculture, climate change, and disaster management. Website: <https://sentinel.esa.int/web/sentinel/missions>
- AquaSpy offers a soil moisture monitoring system that includes sensors and a cloud-based platform for data analysis. The probes measure soil moisture, temperature, and electrical conductivity at different depths, enabling farmers to optimize irrigation schedules and improve water use efficiency. Website: <https://aquaspy.com/>
- The Arable Mark IoT device combines various sensors, including soil moisture, to collect data on crop health, growth, and weather conditions. This information helps farmers optimize crop management, reduce input costs, and improve yield potential. Website: <https://www.arable.com/products/mark>
- The Apogee Instruments' Soil CO₂ Concentration Sensor measures soil carbon dioxide concentration, which is an essential parameter for understanding soil respiration and microbial activity. This sensor helps researchers and agronomists monitor soil health and fertility. Website: <https://www.apogeeinstruments.com/soil-co2/>
- The SoilOptix high-definition soil sensor by SoilOptix Inc. provides a detailed understanding of soil properties, such as texture, organic matter, and nutrient levels, by combining gamma-ray and visible/near-infrared spectroscopy. This information enables

precision agriculture practices, such as site-specific fertilizer applications and variable-rate seeding. Website: <https://soiloptix.com/soiloptix/>

The Hydrosense II soil moisture monitoring system by Campbell Scientific combines a handheld reader with soil moisture probes for quick, portable, and non-destructive measurements. The system provides farmers and researchers with real-time data on soil moisture content to help make informed decisions about irrigation and water management. Website: <https://www.campbellsci.com/hydrosense>

These examples demonstrate the wide range of available technologies and products for soil moisture and chemistry monitoring in the context of agriculture and environmental management. These solutions offer farmers, researchers, and policymakers' valuable insights into soil conditions, allowing for more efficient and sustainable agricultural practices.

Several sensors and systems are suitable for integration with drones for soil moisture and chemistry monitoring, for examples:

- Parrot Sequoia: As previously mentioned, the Parrot Sequoia is a multispectral sensor designed specifically for agricultural drones. It captures data across four spectral bands (green, red, red edge, and near-infrared), providing information on vegetation health and stress levels. Website: <https://www.parrot.com/business-solutions-us/parrot-professional/parrot-sequoia>
- MicaSense RedEdge-MX: This multispectral camera is suitable for drone-based remote sensing applications in agriculture. It captures data in five spectral bands (blue, green, red, red edge, and near-infrared) and enables detailed analysis of crop health, soil moisture, and nutrient levels. Website: <https://www.micasense.com/rededge-mx>
- Sentera NDVI Single Sensor: This high-precision sensor captures Normalized Difference Vegetation Index (NDVI) data, providing insights into plant health, biomass, and soil moisture. It can be integrated with various drone platforms for agricultural monitoring. Website: <https://sentera.com/sensors/#single>
- Headwall Hyperspec Nano: This hyperspectral imaging sensor can be integrated with drones for soil and vegetation monitoring. Hyperspectral imaging captures data across a wide range of spectral bands, providing detailed information on soil chemistry, moisture, and other properties. Website: <https://www.headwallphotonics.com/hyperspec-nano>
- Agrowing A7RIV Multispectral Solution: This multispectral camera solution is designed for Sony A7RIV cameras and includes modified lenses for capturing data in specific spectral bands. When integrated with a drone, it can provide high-resolution images for analyzing soil moisture, chemistry, and vegetation health. Website: <https://agrowing.com/quad-a7riv/>

These drone-compatible sensors and systems offer various capabilities for monitoring soil moisture and chemistry, making them suitable for diverse agricultural applications.

Examples of drones designed specifically for agricultural purposes often feature advanced sensing capabilities and specialized cameras for monitoring soil moisture, chemistry, and vegetation health:

- DJI Agras T-Series: The DJI Agras T-Series drones are designed for agricultural applications, including crop spraying and monitoring. They can be equipped with various sensors and cameras to collect soil moisture, chemistry, and crop health data. Website: <https://www.dji.com/agras-t20>
- senseFly eBee X: The senseFly eBee X is a fixed-wing drone designed for mapping and agricultural monitoring. It can be equipped with various payloads, including multispectral and hyperspectral sensors, to collect soil moisture, chemistry, and vegetation health data. Website: <https://www.sensefly.com/drone/ebee-x-fixed-wing-drone/>

- Parrot Bluegrass Fields: The Parrot Bluegrass Fields is a drone specifically designed for agriculture. It comes with a multispectral sensor (Parrot Sequoia) and a high-resolution RGB camera, providing data on soil moisture, chemistry, and crop health. Website: <https://www.parrot.com/business-solutions-us/parrot-bluegrass-fields>
- PrecisionHawk Lancaster: The PrecisionHawk Lancaster is a fixed-wing drone for agricultural monitoring, capable of carrying multiple sensors for collecting data on soil moisture, chemistry, and vegetation health. Website: <https://www.precisionhawk.com/platforms/lancaster>
- AeroVironment Quantix: The AeroVironment Quantix is a hybrid drone combining the advantages of fixed-wing and multirotor drones. It is designed for agricultural applications and features an integrated multispectral and high-resolution RGB camera for soil and crop health monitoring. Website: <https://www.avdroneanalytics.com/quantix>
- AgEagle RX-60: The AgEagle RX-60 is a fixed-wing drone designed for precision agriculture, with the ability to carry various cameras and sensors to capture soil moisture, chemistry, and crop health data. Website: <https://www.ageagle.com/rx-series-drones>
- DJI Phantom 4 Multispectral: The DJI Phantom 4 Multispectral is designed specifically for agriculture, featuring an integrated multispectral camera for capturing high-resolution imagery for crop health monitoring, soil moisture, and chemistry analysis. Website: <https://www.dji.com/phantom-4-rtk-multispectral>
- Autel Robotics EVO Lite+ AG: The Autel EVO Lite+ AG is a versatile drone designed for agricultural applications, featuring multispectral and RGB cameras for monitoring soil moisture, chemistry, and vegetation health. Website: <https://www.autelrobotics.com/evo-lite-ag>
- Yamaha RMAX: The Yamaha RMAX is a helicopter-style drone designed for agricultural applications, such as crop spraying and monitoring. It can be equipped with various sensors and cameras to capture data on soil moisture, chemistry, and crop health. Website: <https://www.yamaha-motor.com/precisionagriculture/products/unmanned-helicopters/rmax>
- Delair UX11 Ag: The Delair UX11 Ag is a fixed-wing drone designed for agriculture and equipped with multispectral and RGB cameras for capturing high-resolution images for crop health monitoring, soil moisture, and chemistry analysis. Website: <https://delair.aero/precision-agriculture-drone-ux11-ag/>
- WingtraOne: The WingtraOne is a hybrid fixed-wing and multirotor drone designed for aerial mapping and surveying. It can be equipped with various agriculture-specific sensors, such as multispectral and hyperspectral cameras, to monitor soil moisture, chemistry, and crop health. Website: <https://wingtra.com/wingtraone/>
- Altavian Nova F7200: The Altavian Nova F7200 is a fixed-wing drone designed for mapping and surveying applications, including agriculture. It can carry various sensors and cameras to collect data on soil moisture, chemistry, and vegetation health. Website: <https://altavian.com/products/f7200-fixed-wing-drone>

These drones offer diverse capabilities for agricultural monitoring, with options for different types of sensors and cameras. By using these drones, farmers and researchers can collect valuable data on soil moisture, chemistry, and crop health, which can help improve decision-making and optimize agricultural practices.

Selecting the most suitable drone for agricultural applications in West Java, Indonesia, depends on multiple factors, including specific needs, budget, and local regulations, which may impact the choice of drone and the way to operate. Considering the region's diverse terrain, climate, and the types of crops cultivated, the following drones could be suitable:

- DJI Phantom 4 Multispectral: This drone offers a good balance of cost and functionality. It has an integrated multispectral camera, which can capture high-resolution images for monitoring soil moisture, chemistry, and crop health.
- Autel Robotics EVO Lite+ AG: The Autel EVO Lite+ AG is another versatile drone designed for agriculture, featuring multispectral and RGB cameras for monitoring soil moisture, chemistry, and vegetation health. Its compact size makes it easier to transport and operate.
- WingtraOne: The WingtraOne is a hybrid fixed-wing and multirotor drone that combines the benefits of both designs. Its vertical takeoff and landing (VTOL) capability allows it to operate in diverse terrain, and it can cover large areas, making it suitable for large-scale agricultural monitoring.

Additionally, the drone's compatibility with the software for data processing and analysis is also important as some drones come with proprietary software, while others may work with a range of third-party platforms.

DJI and Autel Robotics are popular international brands known for their global presence. It's highly likely that the following drones are available in the Indonesian market:

- DJI Phantom 4 Multispectral: DJI is a well-known drone manufacturer with a global presence, and its products are commonly available in many countries, including Indonesia.
- Autel Robotics EVO Lite+ AG: Autel Robotics is another popular international brand, and its agricultural drones, including the EVO Lite+ AG, might also be available in the Indonesian market.

APPENDIX C

List of Sensors

C List of Sensors

C.1.1 List of Field-Implanted Sensors

Below is a list of soil moisture sensors that can be considered for use.

- 1 Decagon Devices - 5TM Soil Moisture and Temperature Sensor
 - Website: <https://www.metergroup.com/environment/products/5tm-moisture-and-temperature-sensor/>
- 2 Vegetronix - VH400 Soil Moisture Sensor
 - Website: <https://www.vegetronix.com/Products/VH400/>
- 3 Sentek - Drill & Drop Soil Moisture Probe
 - Website: <https://sentektechnologies.com/product/drill-drop/>
- 4 Irrrometer - Watermark Soil Moisture Sensor
 - Website: <https://www.irrometer.com/sensors.html#WATERMARK>
- 5 Campbell Scientific - CS655 Soil Moisture and Temperature Sensor
 - Website: <https://www.campbellsci.com/cs655>
- 6 Acclima - True TDR-315 Soil Moisture Sensor
 - Website: <https://acclima.com/products/soil-moisture-sensor.html>
- 7 Delta-T Devices - SM150T Soil Moisture and Temperature Sensor
 - Website: <https://www.delta-t.co.uk/product/sm150t/>
- 8 Aquacheck - SM150 Soil Moisture Sensor
 - Website: <https://www.aquacheck.co.za/products/sensors/sdi12/soil-moisture-sensor/>
- 9 Meter Group - Teros 12 Soil Moisture and Temperature Sensor
 - Website: <https://www.metergroup.com/environment/products/teros-12-soil-moisture-sensor/>
- 10 Stevens Water - HydraProbe Soil Moisture and Temperature Sensor
 - Website: <https://www.stevenswater.com/sensors/hydraprobe/>
- 11 Spectrum Technologies - WatchDog TDR Soil Moisture Sensor
 - Website: <https://www.specmeters.com/soil-measurements/soil-moisture-sensors/tdr/>
- 12 Soil Scout - Soil Scout H3 Soil Moisture Sensor
 - Website: <https://www.soilscout.com/products>
- 13 Apogee Instruments - GS3 Soil Moisture, Temperature, and Electrical Conductivity Sensor
 - Website: <https://www.apogeeinstruments.com/gs3/>
- 14 GroPoint - GroPoint Profile Soil Moisture Sensor
 - Website: <https://gropoint.com/products/gropoint-profile/>
- 15 ICT International - SM200 Soil Moisture Sensor
 - Website: <http://ictinternational.com/products/sm200-soil-moisture-sensor/>

- 16 Saturas - Saturas Stem Water Potential Sensor
 - Website: <https://www.saturas-ag.com/>
- 17 Aranet - Aranet Soil Moisture and Temperature Sensor
 - Website: <https://aranet.com/product/aranet-soil-moisture-and-temperature-sensor/>
- 18 Toro - Turf Guard Soil Moisture Sensor
 - Website: <https://www.toro.com/en/golf/turf-guard>
- 19 R.S. Hydro - ThetaProbe ML3 Soil Moisture Sensor
 - Website: <https://www.rshydro.co.uk/soil-moisture-sensors/>
- 20 Irromesh - Irrrometer R Soil Moisture Sensor
 - Website: <https://www.irromesh.com/products/r-sensor/>
- 21 Meter Group - EC-5 Soil Moisture Sensor
 - Website: <https://www.metergroup.com/environment/products/ec-5/>
- 22 Netafim - Soil Moisture Monitor System
 - Website: <https://www.netafim.com/en/product/soil-moisture-monitoring/>
- 23 Acclima - True TDR Soil Moisture Sensor
 - Website: <https://www.acclima.com/products/>
- 24 Ranch Systems - RS300 Soil Moisture and Temperature Sensor
 - Website: <https://www.ranchsystems.com/products/sensors/>
- 25 Campbell Scientific - CS650 Soil Volumetric Water Content Sensor
 - Website: <https://www.campbellsci.com/cs650>
- 26 Imko Micromodultechnik - TRIME-PICO 64/32 Soil Moisture Sensor
 - Website: <https://www.imko.de/en/products/moisture/tdr-probes/trime-pico-64-32/>
- 27 Streat Instruments - Soil Water Content Sensor - MoisturePoint®
 - Website: <https://www.streatsahead.com/mp/>
- 28 Davis Instruments - Soil Moisture Sensor
 - Website: <https://www.davisinstruments.com/solution/soil-moisture-sensor/>
- 29 Dynamax - Soil Water Potential Sensor - WPS-12A
 - Website: <https://www.dynamax.com/soil-science/water-potential>
- 30 John Deere - Field Connect Soil Moisture Probe
 - Website: <https://www.deere.com/en/precision-ag/technology-products/field-connect/>

Based on overall market presence and recognition, the following five sensors are commonly mentioned and utilized across various applications and locations. These sensors have a strong presence in the market due to their reliability, accuracy, and range of applications.

- 1 Decagon Devices (now Meter Group) - 5TE Soil Moisture, Temperature, and Electrical Conductivity Sensor
 - Website: <https://www.metergroup.com/environment/products/5te/>
- 2 Vegetronix - VH400 Soil Moisture Sensor
 - Website: <https://www.vegetronix.com/Products/VH400/>
- 3 Sentek - Drill & Drop Soil Moisture Probe
 - Website: <https://sentek.com/products/drill-drop/>

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- 4 Meter Group - EC-5 Soil Moisture Sensor
 - Website: <https://www.metergroup.com/environment/products/ec-5/>
- 5 Campbell Scientific - CS655 Soil Volumetric Water Content Sensor
 - Website: <https://www.campbellsci.com/cs655>

List of field-implanted soil chemistry sensors, including pH, EC, temperature, nutrients, and other soil chemical elements.

- 1 SoilCares (AgroCares) Soil Scanner
 - Website: <https://www.agrocares.com/en/>
 - Measures: pH, EC, temperature, nutrients (N, P, K), organic matter, and more
- 2 Stevens HydraProbe Soil Sensor
 - Website: <https://www.stevenswater.com/>
 - Measures: soil moisture, temperature, EC, and dielectric permittivity
- 3 Sentek EnviroSCAN
 - Website: <https://sentek.com.au/>
 - Measures: soil moisture, temperature, salinity
- 4 SDEC France Field Scout SoilStik pH Meter
 - Website: <https://www.sdec-france.com/>
 - Measures: pH
- 5 Hanna Instruments HI1292D Direct Soil pH Electrode
 - Website: <https://www.hannainst.com/>
 - Measures: pH
- 6 Spectrum Technologies FieldScout TDR 350 Soil Moisture Meter
 - Website: <https://www.specmeters.com/>
 - Measures: soil moisture, EC, temperature
- 7 AquaCheck Soil Moisture Probe
 - Website: <http://www.aquacheck.co.za/>
 - Measures: soil moisture, temperature, and salinity
- 8 Decagon Devices 5TE Soil Moisture Sensor
 - Website: <https://www.metergroup.com/environment/>
 - Measures: soil moisture, temperature, EC
- 9 Apogee Instruments Soil CO₂ Sensor
 - Website: <https://www.apogeeinstruments.com/>
 - Measures: soil CO₂ concentration
- 10 John Deere Field Connect Soil Moisture Probe
 - Website: <https://www.deere.com/en/>
 - Measures: soil moisture, EC, temperature
- 11 Campbell Scientific CS650 Soil Moisture Sensor
 - Website: <https://www.campbellsci.com/>

- Measures: soil moisture, temperature, EC
- 12 Delta-T Devices SM150T Soil Moisture and Temperature Sensor
 - Website: <https://www.delta-t.co.uk/>
 - Measures: soil moisture, temperature
- 13 Adcon SM1 Soil Moisture Probe
 - Website: <https://www.adcon.com/>
 - Measures: soil moisture, temperature, EC
- 14 Vegetronix VH400 Soil Moisture Sensor
 - Website: <https://www.vegetronix.com/>
 - Measures: soil moisture
- 15 HOBOnet T11 Soil Moisture Smart Sensor
 - Website: <https://www.onsetcomp.com/>
 - Measures: soil moisture, temperature
- 16 Irrrometer Watermark Soil Moisture Sensor
 - Website: <https://www.irrometer.com/>
 - Measures: soil moisture
- 17 Edaphic Scientific PR2 Profile Probe
 - Website: <https://www.edaphic.com.au/>
 - Measures: soil moisture, temperature, salinity
- 18 Imko Pico 64 Soil Moisture Profile Probe
 - Website: <https://www.imko.de/>
 - Measures: soil moisture, temperature, EC
- 19 Meter Group TEROS 21 Soil Water Potential Sensor
 - Website: <https://www.metergroup.com/environment/>
 - Measures: soil water potential
- 20 Dynamax TDT Soil Moisture Probe
 - Website: <https://dynamax.com/>
 - Measures: soil moisture, temperature, EC
- 21 Parrot Sequoia+ Multispectral Sensor
 - Website: <https://www.parrot.com/>
 - Measures: chlorophyll content, vegetation indices, and more
- 22 Sentek TriSCAN Probe
 - Website: <https://sentek.com.au/>
 - Measures: soil moisture, temperature, salinity
- 23 Ranch Systems RS300 Soil Moisture, Salinity, and Temperature Sensor
 - Website: <https://www.ranchsystems.com/>
 - Measures: soil moisture, temperature, EC

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- 24 ICT International MP406 Soil Moisture Probe
 - Website: <https://ictinternational.com/>
 - Measures: soil moisture, temperature
- 25 Horiba LAQUA Twin Compact Meter
 - Website: <https://www.horiba.com/>
 - Measures: pH, EC, NO₃⁻, K⁺, Na⁺, Ca²⁺
- 26 Irrrometer Tensiometer
 - Website: <https://www.irrometer.com/>
 - Measures: soil moisture tension
- 27 OTT Hydromet PLS Soil Moisture Probe
 - Website: <https://www.ott.com/>
 - Measures: soil moisture, temperature, EC
- 28 Eijkelkamp Soil & Water Water Content Profile Probe
 - Website: <https://en.eijkelkamp.com/>
 - Measures: soil moisture, temperature, salinity
- 29 Stevens Vitel HydraGO Soil Water Potential Sensor
 - Website: <https://www.stevenswater.com/>
 - Measures: soil water potential
- 30 Dynamax SM150T Soil Moisture and Temperature Sensor
 - Website: <https://dynamax.com/>
 - Measures: soil moisture, temperature

Based on the overall performance, versatility, and suitability the following 5 soil sensors can be considered among the best options:

- 1 Decagon Devices (Meter Group) 5TE Soil Moisture, Temperature, and EC Sensor
 - Website: <https://www.metergroup.com/environment/>
 - Measures: soil moisture, temperature, electrical conductivity (EC)
- 2 Sentek EnviroSCAN Probe
 - Website: <https://sentek.com.au/>
 - Measures: soil moisture, temperature, salinity
- 3 AquaCheck Soil Moisture Probe
 - Website: <https://www.aquacheck.cc/>
 - Measures: soil moisture, temperature, EC
- 4 Edaphic Scientific PR2 Profile Probe
 - Website: <https://www.edaphic.com.au/>
 - Measures: soil moisture, temperature, salinity
- 5 Campbell Scientific CS655 Soil Moisture, Temperature, and EC Sensor
 - Website: <https://www.campbellsci.com/>

- Measures: soil moisture, temperature, EC

C.1.2 List of Drone Based Sensors

Based on their overall features and performance, I would recommend considering the following three drone-based systems:

- 1 DJI Phantom 4 RTK with Sentera 6X Multispectral Sensor
 - Website: <https://www.dji.com/phantom-4-rtk>
 - Website: <https://sentera.com/agriculture/sensors/6x-multispectral-sensor/>
 - The DJI Phantom 4 RTK is a popular and reliable drone that offers excellent flight stability and accuracy. The Sentera 6X multispectral sensor provides high-resolution imagery and data for soil moisture and chemistry analysis.
- 2 Parrot Bluegrass Fields with Parrot Sequoia+ Multispectral Sensor
 - Website: <https://www.parrot.com/business-solutions-us/parrot-bluegrass-fields>
 - Parrot Bluegrass Fields is an all-in-one agriculture drone solution that includes a multispectral sensor, a rugged drone, and easy-to-use data analysis software. The Parrot Sequoia+ multispectral sensor is lightweight and captures high-quality data for soil moisture and chemistry.
- 3 senseFly eBee X with MicaSense RedEdge-MX
 - Website: <https://www.sensefly.com/drones/ebex.html>
 - Website: <https://www.micasense.com/rededge-mx/>
 - The senseFly eBee X is a professional fixed-wing drone with long flight times and coverage capabilities, making it suitable for larger fields. The MicaSense RedEdge-MX is a high-performance multispectral sensor that captures data for soil moisture and chemistry analysis.

C.1.3 List of Satellite Remote Sensing Sensors

Here is a list of 10 satellite-based remote sensing products/systems that provide soil moisture and soil chemistry data:

- 1 NASA Soil Moisture Active Passive (SMAP): Provides global soil moisture data with high spatial resolution. Website: <https://smap.jpl.nasa.gov/>
- 2 European Space Agency (ESA) Soil Moisture and Ocean Salinity (SMOS) mission: Measures global soil moisture using passive microwave sensors. Website: https://www.esa.int/Applications/Observing_the_Earth/SMOS
- 3 NASA Aqua and Terra Moderate Resolution Imaging Spectroradiometer (MODIS): Provides soil moisture data, vegetation indices, and other relevant data for soil chemistry analysis. Website: <https://modis.gsfc.nasa.gov/>
- 4 ESA's Sentinel-2: Offers multispectral data useful for monitoring soil properties and vegetation health. Website: <https://sentinels.copernicus.eu/web/sentinel/missions/sentinel-2>
- 5 USGS Landsat Program: Provides multispectral imagery for land surface and soil properties monitoring. Website: <https://www.usgs.gov/land-resources/nli/landsat>
- 6 ESA's Sentinel-1: Synthetic Aperture Radar (SAR) data for soil moisture mapping and other applications. Website: <https://sentinels.copernicus.eu/web/sentinel/missions/sentinel-1>

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- 7 Copernicus Climate Change Service (C3S) Soil Moisture: Provides historical and near-real-time soil moisture datasets. Website: <https://climate.copernicus.eu/climate-reanalysis>
- 8 RapidEye Satellite System: Offers high-resolution, multispectral data suitable for soil and vegetation analysis. Website: <https://www.planet.com/products/rapideye-archive/>
- 9 GeoEye-1: High-resolution satellite imagery for various applications, including soil and vegetation monitoring. Website: <https://www.maxar.com/space-infrastructure/earth-observation-satellites/geoeye-1>
- 10 DigitalGlobe's WorldView-3: High-resolution multispectral and hyperspectral imagery for detailed soil and vegetation analysis. Website: <https://www.maxar.com/space-infrastructure/earth-observation-satellites/worldview-3>

These satellite-based remote sensing systems provide various types of data that can be used to monitor soil moisture and soil chemistry. Each system has its own unique capabilities, and some may be more suitable for specific applications or regions than others.

Here are the best three satellite remote sensing systems for recent implementation:

- 1 European Space Agency (ESA) Soil Moisture and Ocean Salinity (SMOS) mission
- 2 ESA's Sentinel-2
- 3 USGS Landsat Program

For each system, the supporting systems and costs are as follows:

- 1 ESA SMOS:
 - Supporting Systems: Data from the SMOS satellite is freely available and can be downloaded from ESA's Earth Online platform. You may require GIS software, such as QGIS or ArcGIS, to process and analyze the data.
 - Costs: Data from the SMOS satellite is freely available. However, there might be costs associated with acquiring GIS software, depending on the choice of software and licensing options.
- 2 ESA Sentinel-2:
 - Supporting Systems: Data from the Sentinel-2 satellites is freely available and can be downloaded from the Copernicus Open Access Hub. You may need GIS software, such as QGIS or ArcGIS, to process and analyze the data. Additionally, you may require cloud-based processing platforms, such as Google Earth Engine, to handle the large datasets.
 - Costs: Data from Sentinel-2 is freely available. Costs will be associated with acquiring GIS software and, if needed, using cloud-based processing platforms (depending on their pricing plans).
- 3 USGS Landsat Program:
 - Supporting Systems: Landsat data is freely available and can be downloaded from the USGS EarthExplorer platform. You may require GIS software, such as QGIS or ArcGIS, to process and analyze the data. You might also use cloud-based processing platforms, such as Google Earth Engine, to handle large datasets.
 - Costs: Landsat data is freely available. Costs will be associated with acquiring GIS software and, if needed, using cloud-based processing platforms (depending on their pricing plans).

For all three systems, the satellite data is freely available. The primary costs associated with using these systems will come from acquiring GIS software and using cloud-based

processing platforms if needed. These costs can vary depending on the choice of software and licensing options, as well as the pricing plans of the cloud-based platforms.

C.1.4 List of Combined Approach Technology

Here are ten combined approaches for soil moisture and chemistry sensing, utilizing multiple technologies such as field-implanted sensors, drone-based sensors, and remote sensing data:

- 1 Teralytic Soil Probes and Drones
 - Field-implanted soil probe: Teralytic Soil Probe (Soil NPK, pH, EC, temperature, and moisture)
 - Drone-based system: Drone equipped with multispectral or hyperspectral cameras
 - Website: <https://www.teralytic.com/>
- 2 Sentek EnviroSCAN Probe & Parrot Sequoia+ drone
 - Field-implanted soil probe: Sentek EnviroSCAN (Soil moisture, temperature, and salinity)
 - Drone-based system: Parrot Sequoia+ multispectral sensor mounted on a compatible drone
 - Website: <https://www.sentek.com.au/> & <https://www.parrot.com/business-solutions-us/parrot-sequoia>
- 3 AquaCheck Soil Moisture Probe & MicaSense RedEdge-MX
 - Field-implanted soil probe: AquaCheck Soil Moisture Probe (Soil moisture, temperature, and salinity)
 - Drone-based system: MicaSense RedEdge-MX multispectral camera mounted on a compatible drone
 - Website: <http://www.aquacheck.cc/> & <https://www.micasense.com/rededge-mx/>
- 4 Edaphic Scientific PR2 Profile Probe & Sentera AGX710
 - Field-implanted soil probe: Edaphic Scientific PR2 Profile Probe (Soil moisture)
 - Drone-based system: Sentera AGX710 mounted on a DJI Matrice 200 Series drone
 - Website: <https://www.edaphic.com.au/> & <https://sentera.com/agx710/>
- 5 Meter Group 5TE Soil Sensors & Headwall Hyperspectral Camera
 - Field-implanted soil probe: Meter Group 5TE Soil Moisture, Temperature, and EC Sensor
 - Drone-based system: Headwall Hyperspectral Camera mounted on a compatible drone
 - Website: <https://www.metergroup.com/> & <https://www.headwallphotonics.com/>
- 6 Campbell Scientific CS655 & DJI Phantom 4 Multispectral
 - Field-implanted soil probe: Campbell Scientific CS655 Soil Moisture, Temperature, and EC Sensor

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- Drone-based system: DJI Phantom 4 Multispectral drone with integrated multispectral camera
 - Website: <https://www.campbellsci.com/> & <https://www.dji.com/phantom-4-rtk>
- 7 CropX Soil Sensor & Pix4Dfields Software
- Field-implanted soil probe: CropX Soil Sensor (Soil moisture, temperature, and EC)
 - Remote sensing data: Satellite-based imagery and drone-acquired imagery
 - Software: Pix4Dfields for processing and analyzing imagery data
 - Website: <https://www.cropx.com/> & <https://www.pix4d.com/product/pix4dfields>
- 8 Watermark Soil Moisture Sensor & PrecisionHawk Drones
- Field-implanted soil probe: Watermark Soil Moisture Sensor
 - Drone-based system: PrecisionHawk drone with multispectral or hyperspectral cameras
 - Website: <https://www.irrometer.com/> & <https://www.precisionhawk.com/>
- 9 Arable Mark IoT Platform & DroneDeploy
- Field-implanted sensor: Arable Mark (Weather, Soil, and Plant Health Measurements)
 - Drone-based system: Compatible drone with multispectral or hyperspectral cameras
 - Software: DroneDeploy for drone mission planning, data acquisition, and analysis
 - Website: <https://www.arable.com/> & <https://www.dronedeploy.com/>
- 10 Vadose Zone Monitoring System & Parrot Bluegrass Fields
- Field-implanted soil probe: Vadose Zone Monitoring System (Soil moisture and temperature)
 - Drone-based system: Parrot Bluegrass Fields drone with multispectral sensor and integrated software
 - Website: <https://www.soilmoisture.com/> & <https://www.parrot.com/us/business-solutions/parrot-bluegrass-fields>

C.1.4.1 Combination System

A combination of all three approaches - field-implanted sensors, drone-based sensing, and satellite remote sensing - can provide a comprehensive and robust soil monitoring system for agriculture. Example of how these approaches can be integrated for effective soil moisture and chemistry monitoring in the Sukabumi region, West Java, Indonesia:

- 1 Field-Implanted Sensors: Start by installing field-implanted sensors like the Decagon Devices (Meter Group) 5TE Soil Moisture, Temperature, and EC Sensor or Sentek EnviroSCAN Probe at strategic locations throughout the agricultural field. These sensors will provide continuous, high-resolution data on soil moisture, temperature, and electrical conductivity (EC).
- 2 Drone-Based Sensing: Regularly schedule drone flights equipped with multispectral or hyperspectral cameras, LiDAR, or other relevant sensors to capture data on a broader scale across the entire farm. This data will complement the field-implanted sensors,

providing information on crop health, growth stages, and identifying areas that require attention.

- 3 Satellite Remote Sensing: Access satellite-based remote sensing data, such as from the European Space Agency's (ESA) Sentinel-2, NASA's MODIS, or other available satellite missions, to acquire regional-scale soil moisture, vegetation indices, and land use data. Satellite data can help monitor larger areas and identify trends, patterns, or anomalies that may not be captured by the field-implanted sensors or drone-based sensing.
- 4 Data Integration and Analysis: Combine the data from field-implanted sensors, drone-based sensing, and satellite remote sensing in a Geographic Information System (GIS) or other data processing software. Develop models or algorithms to analyze and visualize the data, identifying correlations between soil moisture, soil chemistry, crop health, and environmental factors.
- 5 Decision Support System (DSS): Implement a Decision Support System (DSS) that integrates the data collected from all three approaches, providing real-time insights and recommendations to farmers and land managers. This could include irrigation scheduling, nutrient management, or other precision agriculture practices tailored to the specific needs of the region.

Three possible combinations of soil moisture and chemistry sensing approaches that can be created and implemented in the field in the Sukabumi region, West Java, Indonesia:

- 1 Field-Implanted Sensors and Drone-Based Sensing
 - Field-Implanted Sensors: Decagon Devices (Meter Group) 5TE Soil Moisture, Temperature, and EC Sensor or Sentek EnviroSCAN Probe
 - Drone-Based Sensing: DJI Phantom 4 RTK equipped with a multispectral camera, such as the Parrot Sequoia or MicaSense RedEdge-MX
- 2 Field-Implanted Sensors and Satellite Remote Sensing
 - Field-Implanted Sensors: AquaCheck Soil Moisture Probe or Campbell Scientific CS655 Soil Moisture, Temperature, and EC Sensor
 - Satellite Remote Sensing: European Space Agency's (ESA) Sentinel-2, NASA's MODIS, or other available satellite missions
- 3 Drone-Based Sensing and Satellite Remote Sensing
 - Drone-Based Sensing: senseFly eBee X equipped with a hyperspectral camera, such as the Headwall Nano-Hyperspec
 - Satellite Remote Sensing: NASA's Soil Moisture Active Passive (SMAP) mission, the ESA's Soil Moisture and Ocean Salinity (SMOS) mission, or other available satellite missions

Three possible combined approaches using field-implanted sensors, drone-based sensing, and satellite remote sensing in the Sukabumi region, West Java, Indonesia:

- 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

- 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
- 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