



Combining Gamma Ray Sensing and Digital Technology for Soil Moisture and Soil Property Mapping: advancing integrated tools for sustainable soil management

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Soil health and moisture availability are critical for increased productivity and sustainable agricultural systems, particularly in the face of increasing environmental variability and land degradation. The Joint FAO/IAEA Centre Coordinated Research Project (CRP) D12015 brings together 12 Member States to advance gamma-ray spectrometry (GRS) as an innovative, non-invasive nuclear technique for high-resolution soil property mapping. The objective is to advance GRS integrated with digital and remote sensing technologies, such as drone and satellite imagery, environmental sensors, and machine learning, for precise and scalable mapping of soil properties including texture, organic carbon, nitrogen, and moisture. These efforts support the evaluation of erosion risk, improve resource efficiency, and strengthen resilient farming systems.

The first Research Coordination Meeting (Vienna, December 2025) established a clear roadmap for advancing GRS as a nuclear tool for soil monitoring. Key priorities include developing standardized and transferable protocols for GRS deployment and calibration across diverse agro-ecological zones, defining minimal datasets for robust conversion models, and validating both empirical and

physics-based predictive approaches for soil physical properties and moisture. The CRP emphasizes the integration of GRS with complementary digital technologies, such as drone-based multispectral and thermal imaging, satellite remote sensing, and geospatial data fusion, to deliver high-resolution soil maps and decision-support tools.

Applications span three primary areas: (i) the synergistic use of stationary and mobile GRS for precision agriculture mapping, (ii) the fusion of GRS and remote sensing to support irrigation efficiency and drought resilience, and (iii) predictive soil property mapping using multi-sensor datasets and machine learning. Discussions highlighted the need for harmonized methodologies, transparent conversion of radionuclide signals to soil attributes, and rigorous uncertainty quantification to ensure reproducibility and trust in science-based GRS evidence. When implemented with rigor and data traceability, GRS offers a transformative pathway for Sustainable and Resilient Agriculture. Planned outputs include illustrated guidelines, validated case studies, and user-friendly decision-support platforms integrating GRS outputs with crop and water management models. These tools will strengthen Member State capacity to apply nuclear and digital technologies for sustainable soil management.