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Homogeneous Soil Management Units

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Executive summary

The EU Soil Monitoring Directive seeks to foster sustainable soil management across Member States. It recommends creating Soil Units (SUs) within designated Soil Districts to facilitate monitoring and governance. Addressing soil and land-use variability requires advanced methods, such as sophisticated statistical tools and integrative models. The quality of national-level data often hampers accurate results. Additionally, limited delegation of authority hampers soil monitoring and policy execution at the territorial level. Establishing 14 soil districts based on the NUTS II classification, incorporating seven soil quality variables along with climatological, land-use, soil element, and lithological data, offers optimal organisation for truly multifunctional soil units. Ensuring consistent, reliable sampling, analytical procedures, and data collection within a unified national system is essential.

Recommendations

- Expansion of the monitoring network;
- Establishment of new maps with basic information adapted to the national reality;
- Redefinition of Soil Units based on this new information;
- Submission of the proposal for the future Soil Units.

Recipient(s) of the policy brief

Secretariat of Agriculture and Rural Development (DGADR).

Introduction and Problem Statement

Rapid soil degradation threatens food and water security, biodiversity, and climate objectives. The proposed European directive on soil monitoring recommends establishing Soil Districts as territorial reference units to enable consistent and regular monitoring across Member States.

In mainland Portugal, the variety of soil types and the complex land use mosaic complicate the formation of uniform units. Additionally, existing historical sampling points like LUCAS are inadequate for comprehensive national monitoring. Hence, a methodological approach is required to (i) delineate Soil Districts and Units using biophysical and administrative criteria and (ii) optimise the selection of sampling points while taking cost constraints into account.

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Analysis / Key Findings

Tackling soil and land-use heterogeneity calls for sophisticated methods, such as advanced statistical techniques and integrative modeling.

Machine learning algorithms, geostatistical analyses, and geographic information systems are essential tools for this task. The suggested methodology evaluates soil quality by considering climatological, land-use, soil element, and lithological data to accurately map multifunctional soil units.

To assess how well various clustering approaches can identify spatially consistent Soil Districts across diverse environmental conditions, four additional algorithms were chosen alongside the EU-recommended Bethel method.

These methods encompass different clustering families: partitioning (k-means), hierarchical (AHC), fuzzy (FCM), and a proximity-based Random Forest approach. Each algorithm type identifies various structures within multidimensional environmental data. Employing this variety of techniques enables a systematic comparison of how assumptions regarding similarity, distance, cluster shape, and neighborhood relationships influence the resulting ground boundaries.

• The Bethel algorithm helps estimate the necessary sample size and number of districts, but it does not provide a direct spatial boundary for the districts.

• In the combination of Random Forest, MDS, and K-means, several tests produced overly broad clusters, sometimes as a single visible cluster, which reduced its effectiveness for delimitation.

• Agglomerative Hierarchical Clustering (AHC), when used on the Soil Map of the Portuguese Environment Agency (APA), revealed 8 clear clusters with logical territorial boundaries and spatial continuity (Figure 1).

Figure 1 – Results of Agglomerative Hierarchical Clustering; with the Soil Map of the APA.

• Fuzzy C-means (FCM) demonstrated effective performance in creating informative territorial divisions while avoiding excessive fragmentation; the combination of NUTS II and Landscape Units revealed an intriguing territorial pattern (Figure 2).

• The most promising solution for sample sizing (Bethel) involves combining simplified NUTS II + CLC and variables such as apparent density 0–10 cm, Cu, N, organic carbon, P, and pH (Figure 3).

Figure 2 – Fuzzy C-means results with NUTS II and Landscape Units

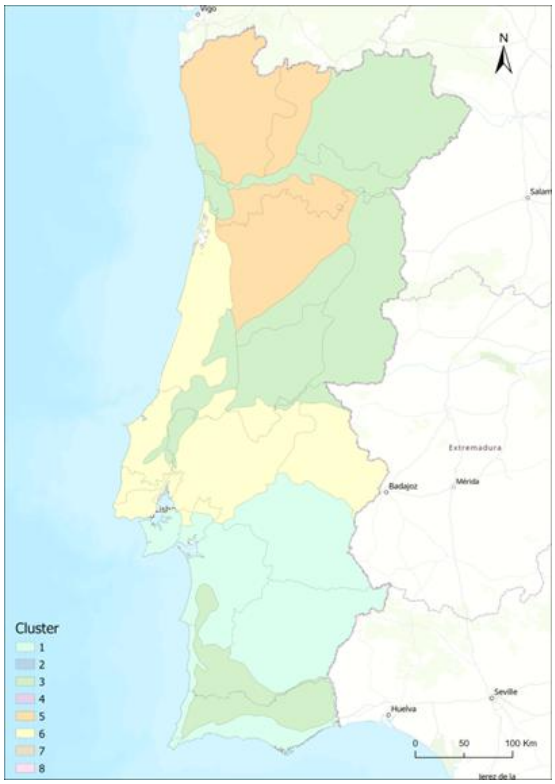
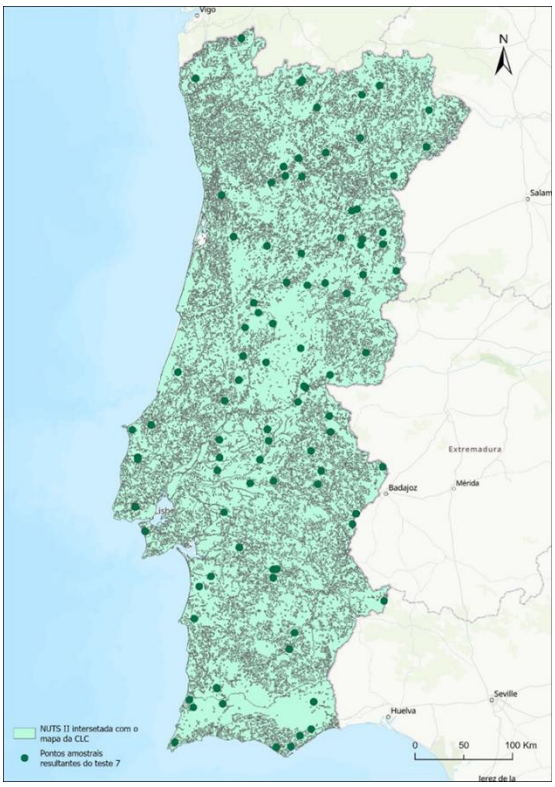


Figure 3 – Result of the test with Bethe's algorithm



Policy Options and Recommendations

Developing a unified national monitoring system with standardized indicators for the European Soil Strategy is crucial. It facilitates consistent implementation, monitoring, and evaluation of soil policies across various levels, from national to regional and local. This approach also allows for testing and comparing different advanced methods.

To meet soil health monitoring obligations, including sample collection, competent authorities of Member States might need to request access to owners' properties, following national rules and procedures. Furthermore, Member States may also require owners to implement measures for sustainable soil management.

Soil analysis data collected periodically from agricultural plots—whether under integrated or organic production supported by the Common Agricultural Policy—can serve as a valuable resource for monitoring soil health across the country's farming regions, effectively creating a soil observatory. To achieve this, it is crucial to guarantee the accuracy and consistency of sample collection, analytical techniques, and data recording within a unified national information system. Coupled with farmers' records of cultural practices on each plot, this information would enable an evaluation of how different farming practices impact soil health.

The primary goal is to create an information system that logs soil sample results collected by different users, supporting efficient

agricultural management. This system should enable the application, monitoring, and assessment of management actions at both the farm level and within rural development policies. Additionally, it aims to establish a governance framework that promotes participation and collaboration among rural development stakeholders.

Option A — Minimum (conservative) model: Delineation based on broad administrative units (e.g., NUTS), with less implementation complexity but less pedological homogeneity.

Option B — Technical-scientific model (recommended): Delineation of Soil Units/Districts based on clustering (AHC/FCM) on integrated variables (soils, land use, climate), preserving contiguity and reducing fragmentation.

Option C — Operational hybrid model: Delineation by AHC/FCM and point sizing by Bethel, allowing a balance of scientific robustness, operability, and costs.

Priority recommendations:

• Establish, in the short term, an operational proposal for Soil Units/Districts for mainland Portugal, supported by clustering methods (AHC/FCM), as a basis for the national monitoring network.

• Adopt a hybrid approach: (i) spatial delimitation by AHC/FCM; (ii) sizing of sampling points by district using the Bethel algorithm, ensuring cost efficiency and representative coverage.

• Prioritize the systematic integration of LUCAS (soil properties and pollutants), climate and land use (CLC) data into reproducible GIS workflows, ensuring harmonization and periodic updates.

Conclusion

To meet soil health monitoring requirements for sample collection, Member State authorities can request access to landowners' properties in line with national rules and procedures. They may also require landowners to implement measures promoting sustainable soil management. Data from periodic soil analyses on agricultural plots—covering both integrated and organic farming methods supported by the Common Agricultural Policy—can serve as a soil observatory, helping to monitor soil health across the country's agricultural regions.

To reach this goal, it is crucial to ensure consistency and standardisation in sample collection procedures, analytical methods, and data gathering within a national information system. When combined with farmers' recorded data on agricultural practices for each plot, this information enables an assessment of how these practices influence soil health.

Creating Soil Districts/Units is essential for implementing future European laws and enhancing national soil monitoring efforts. This thesis shows that hierarchical and fuzzy clustering methods are especially effective for defining meaningful territorial boundaries, and should be combined with techniques like Bethel to improve sample design. Proper implementation requires field validation, clear governance, and regular updates to the database.

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